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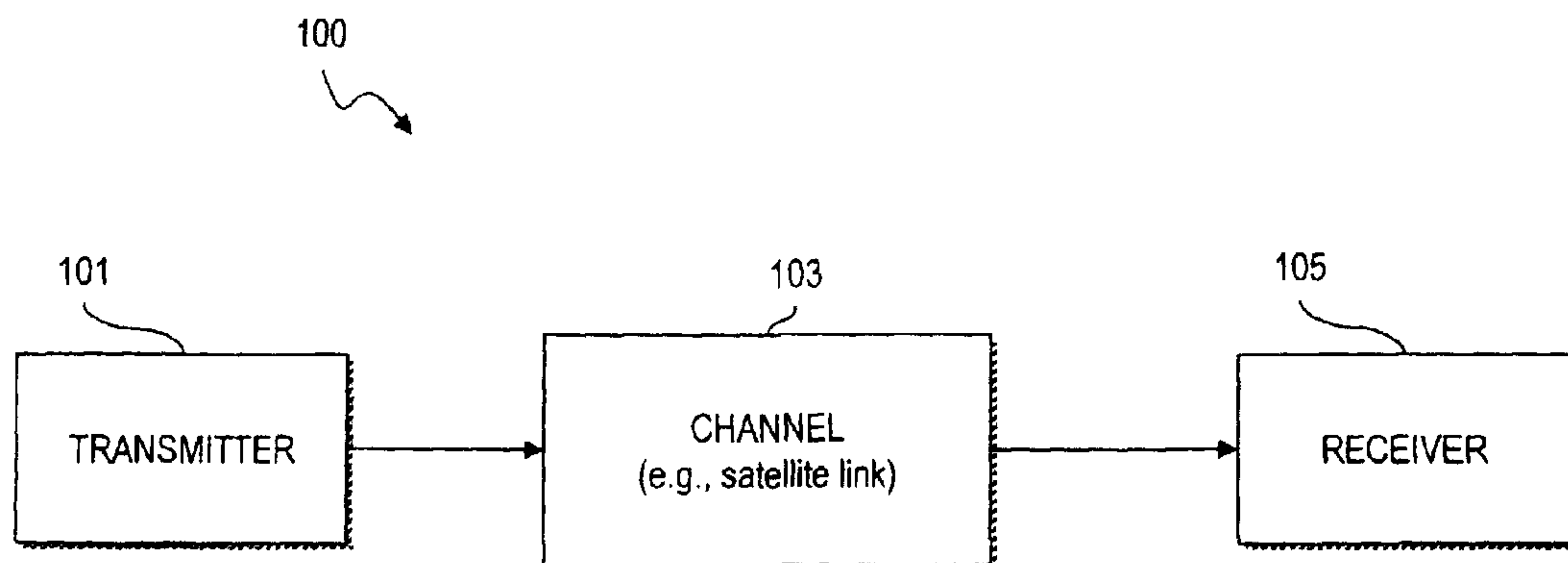
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(54) Titre : METHODE ET SYSTEME FOURNISSANT DES CODES DE CONTROLE DE PARITE A FAIBLE DENSITE ET A COURTE LONGUEUR DE BLOCS POUR APPLICATIONS DE COMMUNICATIONS SATELLITAIRES A LARGE BANDE

(54) Title: METHOD AND SYSTEM FOR PROVIDING SHORT BLOCK LENGTH LOW DENSITY PARITY CHECK (LDPC) CODES IN SUPPORT OF BROADBAND SATELLITE APPLICATIONS



(57) Abrégé/Abstract:

An approach is provided for encoding short frame length Low Density Parity Check (LDPC) codes. An encoder (203) generates a LDPC code having an outer Bose Chaudhuri Hocquenghem (BCH) code. Structure is imposed on the LDPC codes by restricting portion part of the parity check matrix to be lower triangular and/or satisfying other requirements such that the communication between bit nodes and check nodes of the decoder (305) is simplified. Further, a cyclic redundancy check (CRC) encoder (209) is supplied to encode the input signal according to a CRC code. This approach has particular application in digital video broadcast services over satellite.

ABSTRACT OF THE DISCLOSURE

[58] An approach is provided for encoding short frame length Low Density Parity Check (LDPC) codes. An encoder (203) generates a LDPC code having an outer Bose Chaudhuri Hocquenghem (BCH) code. Structure is imposed on the LDPC codes by restricting portion part of the parity check matrix to be lower triangular and/or satisfying other requirements such that the communication between bit nodes and check nodes of the decoder (305) is simplified. Further, a cyclic redundancy check (CRC) encoder (209) is supplied to encode the input signal according to a CRC code. This approach has particular application in digital video broadcast services over satellite.

**METHOD AND SYSTEM FOR PROVIDING
SHORT BLOCK LENGTH LOW DENSITY PARITY CHECK (LDPC) CODES
IN SUPPORT OF BROADBAND SATELLITE APPLICATIONS**

FIELD OF THE INVENTION

[01] The present invention relates to communication systems, and more particularly to coded systems.

BACKGROUND OF THE INVENTION

[02] Communication systems employ coding to ensure reliable communication across noisy communication channels. For example, in a wireless (or radio) system, such as a satellite network, noise sources abound, from geographic and environmental factors. These communication channels exhibit a fixed capacity that can be expressed in terms of bits per symbol at certain signal to noise ratio (SNR), defining a theoretical upper limit (known as the Shannon limit). As a result, coding design has aimed to achieve rates approaching this Shannon limit. This objective is particularly germane to bandwidth constrained satellite systems. One such class of codes that approach the Shannon limit is Low Density Parity Check (LDPC) codes.

[03] Traditionally, LDPC codes have not been widely deployed because of a number of drawbacks. One drawback is that the LDPC encoding technique is highly complex. Encoding an LDPC code using its generator matrix would require storing a very large, non-sparse matrix. Additionally, LDPC codes require large blocks to be effective; consequently, even though parity check matrices of LDPC codes are sparse, storing these matrices is problematic.

[04] From an implementation perspective, a number of challenges are confronted. For example, storage is an important reason why LDPC codes have not become widespread in practice. Length LDPC codes, thus, require greater storage space. Also, a key challenge in LDPC code implementation has been how to achieve the connection network between several processing engines (nodes) in the decoder. Further, the computational load in the decoding process, specifically the check node operations, poses a problem.

[05] Therefore, there is a need for an LDPC communication system that employs simple encoding and decoding processes. There is also a need for using LDPC codes efficiently to support high data rates, without introducing greater complexity. There is also a need to improve performance of LDPC encoders and decoders. There is also a need to minimize storage requirements for implementing LDPC coding.

SUMMARY OF THE INVENTION

[06] These and other needs are addressed by the present invention, wherein an approach for encoding short block length Low Density Parity Check (LDPC) codes is provided. An encoder generates a LDPC code having an outer Bose Chaudhuri Hocquenghem (BCH) code according to one of Tables 1-7 for transmission as the LDPC coded signal. Each of the Tables 1-7 specifies the address of parity bit accumulators. Structure is imposed on the LDPC codes by restricting portion part of the parity check matrix to be lower triangular and/or satisfying other requirements such that the communication between bit nodes and check nodes of the decoder is simplified. Further, a cyclic redundancy check (CRC) encoder is supplied to encode the input signal according to a CRC code. The approach advantageously provides expedient encoding as well as decoding of LDPC codes, while minimizing storage and processing resources.

[07] According to another aspect of an embodiment of the present invention, the LDPC codes are represented by signals that are modulated according to a signal constellation that includes one of 8-PSK (Phase Shift Keying), 16-QAM (Quadrature Amplitude Modulation), QPSK (Quadrature Phase Shift Keying), 16-APSK (Amplitude Phase Shift Keying) and 32-APSK.

[08] According to another aspect of an embodiment of the present invention, the modulated LDPC coded signal is transmitted over a satellite link in support of a broadband satellite application.

[09] According to yet another aspect of an embodiment of the present invention, the BCH outer code is based on a generator polynomial of:

$$\begin{aligned}
 g(x) = & (1+x+x^3+x^5+x^{14}) \times (1+x^6+x^8+x^{11}+x^{14}) \times (1+x+x^2+x^6+x^9+x^{10}+x^{14}) \times \\
 & (1+x^4+x^7+x^8+x^{10}+x^{12}+x^{14}) \times (1+x^2+x^4+x^6+x^8+x^9+x^{11}+x^{13}+x^{14}) \times \\
 & (1+x^3+x^7+x^8+x^9+x^{13}+x^{14}) \times (1+x^2+x^5+x^6+x^7+x^{10}+x^{11}+x^{13}+x^{14}) \times \\
 & (1+x^5+x^8+x^9+x^{10}+x^{11}+x^{14}) \times (1+x+x^2+x^3+x^9+x^{10}+x^{14}) \times (1+x^3+x^6+x^9+x^{11}+x^{12}+x^{14}) \times \\
 & (1+x^4+x^{11}+x^{12}+x^{14}) \times (1+x+x^2+x^3+x^5+x^6+x^7+x^8+x^{10}+x^{13}+x^{14}).
 \end{aligned}$$

[09A] In accordance with an aspect of the invention, there is provided a method comprising:

decoding an encoded signal that was encoded according to a Low Density Parity Check (LDPC) code by accumulating bits at parity bit addresses as specified by any one of Tables 1-10 for transmission as an LDPC coded signal, wherein parity bits, p_i , are

- 3a -

determined according to $p_i = p_i \oplus p_{i-1}$, $i = 1, 2, \dots, n_{ldpc} - k_{ldpc} - 1$, k_{ldpc} being information block size and n_{ldpc} being codeword size:

Address of Parity Bit Accumulators (Shortened from Rate 1/2)							
20	712	2386	6354	4061	1062	5045	5158
21	2543	5748	4822	2348	3089	6328	5876
22	926	5701	269	3693	2438	3190	3507
23	2802	4520	3577	5324	1091	4667	4449
24	5140	2003	1263	4742	6497	1185	6202
0	4046	6934					
1	2855	66					
2	6694	212					
3	3439	1158					
4	3850	4422					
5	5924	290					
6	1467	4049					
7	7820	2242					
8	4606	3080					
9	4633	7877					
10	3884	6868					
11	8935	4996					
12	3028	764					
13	5988	1057					
14	7411	3450					

Table 1

- 3b -

Address of Parity Bit Accumulators (Rate 3/5)												
2765	5713	6426	3596	1374	4811	2182	544	3394	2840	4310	771	
4951	211	2208	723	1246	2928	398	5739	265	5601	5993	2615	
210	4730	5777	3096	4282	6238	4939	1119	6463	5298	6320	4016	
4167	2063	4757	3157	5664	3956	6045	563	4284	2441	3412	6334	
4201	2428	4474	59	1721	736	2997	428	3807	1513	4732	6195	
2670	3081	5139	3736	1999	5889	4362	3806	4534	5409	6384	5809	
5516	1622	2906	3285	1257	5797	3816	817	875	2311	3543	1205	
4244	2184	5415	1705	5642	4886	2333	287	1848	1121	3595	6022	
2142	2830	4069	5654	1295	2951	3919	1356	884	1786	396	4738	
0	2161	2653										
1	1380	1461										
2	2502	3707										
3	3971	1057										
4	5985	6062										
5	1733	6028										
6	3786	1936										
7	4292	956										
8	5692	3417										
9	266	4878										
10	4913	3247										
11	4763	3937										
12	3590	2903										
13	2566	4215										
14	5208	4707										
15	3940	3388										
16	5109	4556										
17	4908	4177										

Table 2

- 3c -

Address of Parity Bit Accumulators (Rate 2/3)												
0	2084	1613	1548	1286	1460	3196	4297	2481	3369	3451	4620	2622
1	122	1516	3448	2880	1407	1847	3799	3529	373	971	4358	3108
2	259	3399	929	2650	864	3996	3833	107	5287	164	3125	2350
3	342	3529										
4	4198	2147										
5	1880	4836										
6	3864	4910										
7	243	1542										
8	3011	1436										
9	2167	2512										
10	4606	1003										
11	2835	705										
12	3426	2365										
13	3848	2474										
14	1360	1743										
0	163	2536										
1	2583	1180										
2	1542	509										
3	4418	1005										
4	5212	5117										
5	2155	2922										
6	347	2696										
7	226	4296										
8	1560	487										
9	3926	1640										
10	149	2928										
11	2364	563										
12	635	688										
13	231	1684										
14	1129	3894										

Table 3

- 3d -

Address of Parity Bit Accumulators (Shortened from Rate 3/4)										
3	3198	478	4207	1481	1009	2616	1924	3437	554	683 1801
4	2681	2135								
5	3107	4027								
6	2637	3373								
7	3830	3449								
8	4129	2060								
9	4184	2742								
10	3946	1070								
11	2239	984								
0	1458	3031								
1	3003	1328								
2	1137	1716								
3	132	3725								
4	1817	638								
5	1774	3447								
6	3632	1257								
7	542	3694								
8	1015	1945								
9	1948	412								
10	995	2238								
11	4141	1907								
0	2480	3079								
1	3021	1088								
2	713	1379								
3	997	3903								
4	2323	3361								
5	1110	986								
6	2532	142								
7	1690	2405								
8	1298	1881								
9	615	174								
10	1648	3112								
11	1415	2808								

Table 4

Address of Parity Bit Accumulators (Shortened from Rate 4/5)	
5 896 1565	
6 2493 184	
7 212 3210	
8 727 1339	
9 3428 612	
0 2663 1947	
1 230 2695	
2 2025 2794	
3 3039 283	
4 862 2889	
5 376 2110	
6 2034 2286	
7 951 2068	
8 3108 3542	
9 307 1421	
0 2272 1197	
1 1800 3280	
2 331 2308	
3 465 2552	
4 1038 2479	
5 1383 343	
6 94 236	
7 2619 121	
8 1497 2774	
9 2116 1855	
0 722 1584	
1 2767 1881	
2 2701 1610	
3 3283 1732	
4 168 1099	
5 3074 243	
6 3460 945	
7 2049 1746	
8 566 1427	
9 3545 1168	

Table 5

Address of Parity Bit Accumulators (Shortened from Rate 5/6)									
3	2409	499	1481	908	559	716	1270	333	2508
4	2447	1926							
5	414	1224							
6	2114	842							
7	212	573							
0	2383	2112							
1	2286	2348							
2	545	819							
3	1264	143							
4	1701	2258							
5	964	166							
6	114	2413							
7	2243	81							
0	1245	1581							
1	775	169							
2	1696	1104							
3	1914	2831							
4	532	1450							
5	91	974							
6	497	2228							
7	2326	1579							
0	2482	256							
1	1117	1261							
2	1257	1658							
3	1478	1225							
4	2511	980							
5	2320	2675							
6	435	1278							
7	228	503							
0	1885	2369							
1	57	483							
2	838	1050							
3	1231	1990							
4	1738	68							
5	2392	951							
6	163	645							
7	2644	1704							

Table 6

- 3g -

Address of Parity Bit Accumulators (Rate 8/9)	
0 1558 712 805	
1 1450 873 1337	
2 1741 1129 1184	
3 294 806 1566	
4 482 605 923	
0 926 1578	
1 777 1374	
2 608 151	
3 1195 210	
4 1484 692	
0 427 488	
1 828 1124	
2 874 1366	
3 1500 835	
4 1496 502	
0 1006 1701	
1 1155 97	
2 657 1403	
3 1453 624	
4 429 1495	
0 809 385	
1 367 151	
2 1323 202	
3 960 318	
4 1451 1039	
0 1098 1722	
1 1015 1428	
2 1261 1564	
3 544 1190	
4 1472 1246	
0 508 630	
1 421 1704	
2 284 898	
3 392 577	
4 1155 556	
0 631 1000	
1 732 1368	
2 1328 329	
3 1515 506	
4 1104 1172	

Table 7

- 3h -

Address of Parity Bit Accumulators (Rate 1/3)												
416	8909	4156	3216	3112	2560	2912	6405	8593	4969	6723	6912	
8978	3011	4339	9312	6396	2957	7288	5485	6031	10218	2226	3575	
3383	10059	1114	10008	10147	9384	4290	434	5139	3536	1965	2291	
2797	3693	7615	7077	743	1941	8716	6215	3840	5140	4582	5420	
6110	8551	1515	7404	4879	4946	5383	1831	3441	9569	10472	4306	
1505	5682	7778										
7172	6830	6623										
7281	3941	3505										
10270	8669	914										
3622	7563	9388										
9930	5058	4554										
4844	9609	2707										
6883	3237	1714										
4768	3878	10017										
10127	3334	8267										

Table 8

Address of Parity Bit Accumulators (Shortened from Rate 1/4)												
6295	9626	304	7695	4839	4936	1660	144	11203	5567	6347	12557	
10691	4988	3859	3734	3071	3494	7687	10313	5964	8069	8296	11090	
10774	3613	5208	11177	7676	3549	8746	6583	7239	12265	2674	4292	
11869	3708	5981	8718	4908	10650	6805	3334	2627	10461	9285	11120	
7844	3079	10773										
3385	10854	5747										
1360	12010	12202										
6189	4241	2343										
9840	12726	4977										

Table 9

Address of Parity Bit Accumulators (Rate 2/5)											
5650	4143	8750	583	6720	8071	635	1767	1344	6922	738	6658
5696	1685	3207	415	7019	5023	5608	2605	857	6915	1770	8016
3992	771	2190	7258	8970	7792	1802	1866	6137	8841	886	1931
4108	3781	7577	6810	9322	8226	5396	5867	4428	8827	7766	2254
4247	888	4367	8821	9660	324	5864	4774	227	7889	6405	8963
9693	500	2520	2227	1811	9330	1928	5140	4030	4824	806	3134
1652	8171	1435									
3366	6543	3745									
9286	8509	4645									
7397	5790	8972									
6597	4422	1799									
9276	4041	3847									
8683	7378	4946									
5348	1993	9186									
6724	9015	5646									
4502	4439	8474									
5107	7342	9442									
1387	8910	2660									

Table 10.

[09B] In accordance with another aspect of the present invention, there is provided an apparatus comprising:

circuitry configured to decode an encoded signal that was encoded according to a Low Density Parity Check (LDPC) code by accumulating bits at parity bit addresses as specified by any one of Tables 1-10 for transmission as an LDPC coded signal, wherein parity bits, p_i , are determined according to

$$p_i = p_i \oplus p_{i-1}, \quad i = 1, 2, \dots, n_{ldpc} - k_{ldpc} - 1, \quad k_{ldpc} \text{ being information block size and } n_{ldpc}$$

being codeword size:

- 3j -

Address of Parity Bit Accumulators (Shortened from Rate 1/2)									
20	712	2386	6354	4061	1062	5045	5158		
21	2543	5748	4822	2348	3089	6328	5876		
22	926	5701	269	3693	2438	3190	3507		
23	2802	4520	3577	5324	1091	4667	4449		
24	5140	2003	1263	4742	6497	1185	6202		
0	4046	6934							
1	2855	66							
2	6694	212							
3	3439	1158							
4	3850	4422							
5	5924	290							
6	1467	4049							
7	7820	2242							
8	4606	3080							
9	4633	7877							
10	3884	6868							
11	8935	4996							
12	3028	764							
13	5988	1057							
14	7411	3450							

Table 1

- 3k -

Address of Parity Bit Accumulators (Rate 3/5)												
2765	5713	6426	3596	1374	4811	2182	544	3394	2840	4310	771	
4951	211	2208	723	1246	2928	398	5739	265	5601	5993	2615	
210	4730	5777	3096	4282	6238	4939	1119	6463	5298	6320	4016	
4167	2063	4757	3157	5664	3956	6045	563	4284	2441	3412	6334	
4201	2428	4474	59	1721	736	2997	428	3807	1513	4732	6195	
2670	3081	5139	3736	1999	5889	4362	3806	4534	5409	6384	5809	
5516	1622	2906	3285	1257	5797	3816	817	875	2311	3543	1205	
4244	2184	5415	1705	5642	4886	2333	287	1848	1121	3595	6022	
2142	2830	4069	5654	1295	2951	3919	1356	884	1786	396	4738	
0	2161	2653										
1	1380	1461										
2	2502	3707										
3	3971	1057										
4	5985	6062										
5	1733	6028										
6	3786	1936										
7	4292	956										
8	5692	3417										
9	266	4878										
10	4913	3247										
11	4763	3937										
12	3590	2903										
13	2566	4215										
14	5208	4707										
15	3940	3388										
16	5109	4556										
17	4908	4177										

Table 2

Address of Parity Bit Accumulators (Rate 2/3)												
0	2084	1613	1548	1286	1460	3196	4297	2481	3369	3451	4620	2622
1	122	1516	3448	2880	1407	1847	3799	3529	373	971	4358	3108
2	259	3399	929	2650	864	3996	3833	107	5287	164	3125	2350
3	342	3529										
4	4198	2147										
5	1880	4836										
6	3864	4910										
7	243	1542										
8	3011	1436										
9	2167	2512										
10	4606	1003										
11	2835	705										
12	3426	2365										
13	3848	2474										
14	1360	1743										
0	163	2536										
1	2583	1180										
2	1542	509										
3	4418	1005										
4	5212	5117										
5	2155	2922										
6	347	2696										
7	226	4296										
8	1560	487										
9	3926	1640										
10	149	2928										
11	2364	563										
12	635	688										
13	231	1684										
14	1129	3894										

Table 3

- 3m -

Address of Parity Bit Accumulators (Shortened from Rate 3/4)										
3	3198	478	4207	1481	1009	2616	1924	3437	554	683 1801
4	2681	2135								
5	3107	4027								
6	2637	3373								
7	3830	3449								
8	4129	2060								
9	4184	2742								
10	3946	1070								
11	2239	984								
0	1458	3031								
1	3003	1328								
2	1137	1716								
3	132	3725								
4	1817	638								
5	1774	3447								
6	3632	1257								
7	542	3694								
8	1015	1945								
9	1948	412								
10	995	2238								
11	4141	1907								
0	2480	3079								
1	3021	1088								
2	713	1379								
3	997	3903								
4	2323	3361								
5	1110	986								
6	2532	142								
7	1690	2405								
8	1298	1881								
9	615	174								
10	1648	3112								
11	1415	2808								

Table 4

Address of Parity Bit Accumulators (Shortened from Rate 4/5)	
5 896 1565	
6 2493 184	
7 212 3210	
8 727 1339	
9 3428 612	
0 2663 1947	
1 230 2695	
2 2025 2794	
3 3039 283	
4 862 2889	
5 376 2110	
6 2034 2286	
7 951 2068	
8 3108 3542	
9 307 1421	
0 2272 1197	
1 1800 3280	
2 331 2308	
3 465 2552	
4 1038 2479	
5 1383 343	
6 94 236	
7 2619 121	
8 1497 2774	
9 2116 1855	
0 722 1584	
1 2767 1881	
2 2701 1610	
3 3283 1732	
4 168 1099	
5 3074 243	
6 3460 945	
7 2049 1746	
8 566 1427	
9 3545 1168	

Table 5

Address of Parity Bit Accumulators (Shortened from Rate 5/6)										
3	2409	499	1481	908	559	716	1270	333	2508	2264 1702 2805
4	2447	1926								
5	414	1224								
6	2114	842								
7	212	573								
0	2383	2112								
1	2286	2348								
2	545	819								
3	1264	143								
4	1701	2258								
5	964	166								
6	114	2413								
7	2243	81								
0	1245	1581								
1	775	169								
2	1696	1104								
3	1914	2831								
4	532	1450								
5	91	974								
6	497	2228								
7	2326	1579								
0	2482	256								
1	1117	1261								
2	1257	1658								
3	1478	1225								
4	2511	980								
5	2320	2675								
6	435	1278								
7	228	503								
0	1885	2369								
1	57	483								
2	838	1050								
3	1231	1990								
4	1738	68								
5	2392	951								
6	163	645								
7	2644	1704								

Table 6

- 3p -

Address of Parity Bit Accumulators (Rate 8/9)	
0	1558 712 805
1	1450 873 1337
2	1741 1129 1184
3	294 806 1566
4	482 605 923
0	926 1578
1	777 1374
2	608 151
3	1195 210
4	1484 692
0	427 488
1	828 1124
2	874 1366
3	1500 835
4	1496 502
0	1006 1701
1	1155 97
2	657 1403
3	1453 624
4	429 1495
0	809 385
1	367 151
2	1323 202
3	960 318
4	1451 1039
0	1098 1722
1	1015 1428
2	1261 1564
3	544 1190
4	1472 1246
0	508 630
1	421 1704
2	284 898
3	392 577
4	1155 556
0	631 1000
1	732 1368
2	1328 329
3	1515 506
4	1104 1172

Table 7

- 3q -

Address of Parity Bit Accumulators (Rate 1/3)												
416	8909	4156	3216	3112	2560	2912	6405	8593	4969	6723	6912	
8978	3011	4339	9312	6396	2957	7288	5485	6031	10218	2226	3575	
3383	10059	1114	10008	10147	9384	4290	434	5139	3536	1965	2291	
2797	3693	7615	7077	743	1941	8716	6215	3840	5140	4582	5420	
6110	8551	1515	7404	4879	4946	5383	1831	3441	9569	10472	4306	
1505	5682	7778										
7172	6830	6623										
7281	3941	3505										
10270	8669	914										
3622	7563	9388										
9930	5058	4554										
4844	9609	2707										
6883	3237	1714										
4768	3878	10017										
10127	3334	8267										

Table 8

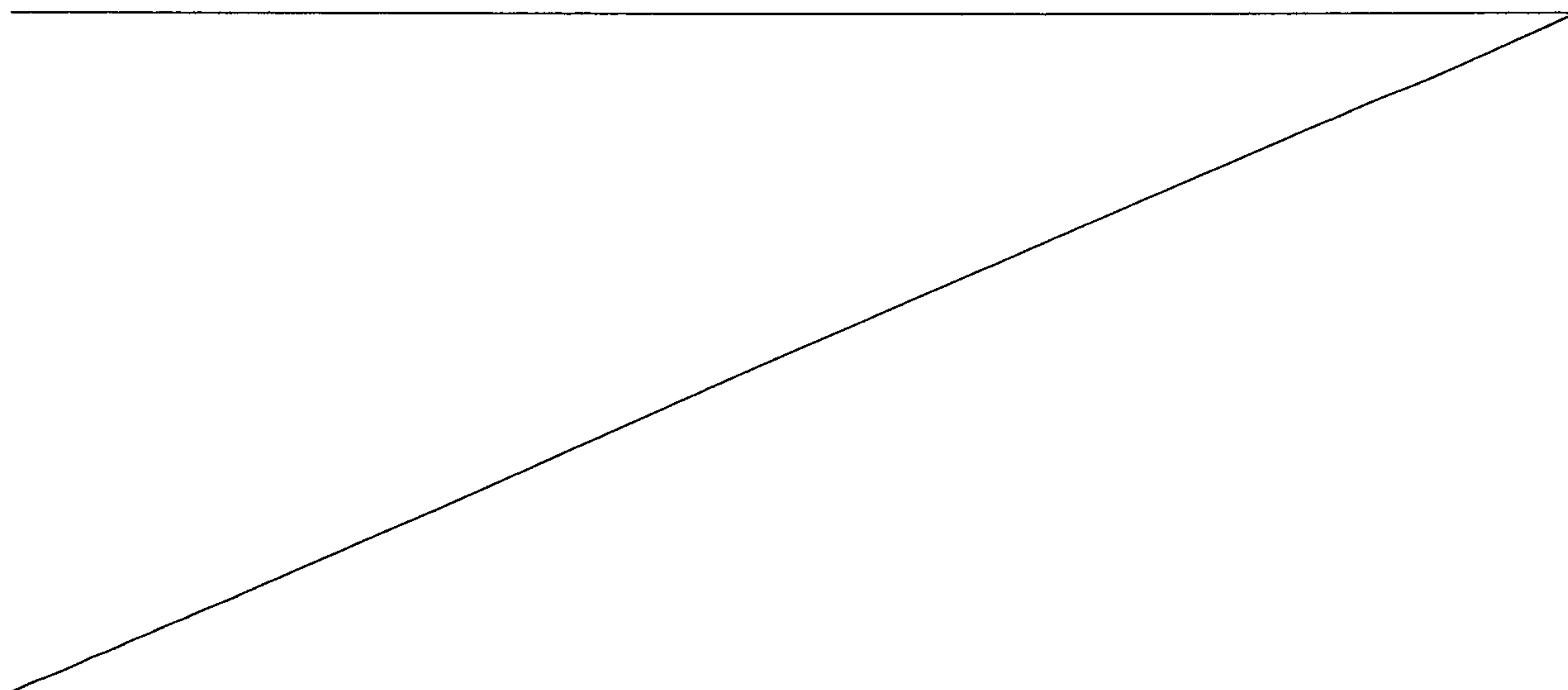
Address of Parity Bit Accumulators (Shortened from Rate 1/4)												
6295	9626	304	7695	4839	4936	1660	144	11203	5567	6347	12557	
10691	4988	3859	3734	3071	3494	7687	10313	5964	8069	8296	11090	
10774	3613	5208	11177	7676	3549	8746	6583	7239	12265	2674	4292	
11869	3708	5981	8718	4908	10650	6805	3334	2627	10461	9285	11120	
7844	3079	10773										
3385	10854	5747										
1360	12010	12202										
6189	4241	2343										
9840	12726	4977										

Table 9

Address of Parity Bit Accumulators (Rate 2/5)															
5650	4143	8750	583	6720	8071	635	1767	1344	6922	738	6658				
5696	1685	3207	415	7019	5023	5608	2605	857	6915	1770	8016				
3992	771	2190	7258	8970	7792	1802	1866	6137	8841	886	1931				
4108	3781	7577	6810	9322	8226	5396	5867	4428	8827	7766	2254				
4247	888	4367	8821	9660	324	5864	4774	227	7889	6405	8963				
9693	500	2520	2227	1811	9330	1928	5140	4030	4824	806	3134				
1652	8171	1435													
3366	6543	3745													
9286	8509	4645													
7397	5790	8972													
6597	4422	1799													
9276	4041	3847													
8683	7378	4946													
5348	1993	9186													
6724	9015	5646													
4502	4439	8474													
5107	7342	9442													
1387	8910	2660													

Table 10

[10] Still other aspects, features, and advantages of the present invention are readily apparent from the following detailed description, simply by illustrating a number of particular embodiments and implementations, including the best mode contemplated for carrying out



the present invention. The present invention is also capable of other and different embodiments, and its several details can be modified in various obvious respects, all without departing from the scope of the present invention. Accordingly, the drawing and description are to be regarded as illustrative in nature, and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[11] The present invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements and in which:

[12] FIG. 1 is a diagram of a communications system configured to utilize Low Density Parity Check (LDPC) codes, according to an embodiment of the present invention;

[13] FIGs. 2A and 2B are diagrams of exemplary LDPC encoders deployed in the transmitter of FIG. 1;

[14] FIG. 2C is a flowchart of the encoding process of the LDPC encoder of FIG. 2B for generating short frame length LDPC codes, according to one embodiment of the present invention;

[15] FIG. 3 is a diagram of an exemplary receiver in the system of FIG. 1;

[16] FIG. 4 is a diagram of a sparse parity check matrix, in accordance with an embodiment of the present invention;

[17] FIG. 5 is a diagram of a bipartite graph of an LDPC code of the matrix of FIG. 4;

[18] FIG. 6 is a diagram of a sub-matrix of a sparse parity check matrix, wherein the sub-matrix contains parity check values restricted to the lower triangular region, according to an embodiment of the present invention; and

[19] FIG. 7 is a diagram of a computer system that can perform the LDPC encoding process, in accordance with embodiments of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[20] A system, method, and software for efficiently encoding short frame length Low Density Parity Check (LDPC) codes are described. In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It is apparent, however, to one skilled in the art that the present invention may be practiced without these specific details or with an equivalent arrangement. In other instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring the present invention.

[21] FIG. 1 is a diagram of a communications system configured to utilize Low Density Parity Check (LDPC) codes, according to an embodiment of the present invention. A digital communications system 100 includes a transmitter 101 that generates signal waveforms across a communication channel 103 to a receiver 105. In this discrete communications system 100, the transmitter 101 has a message source that produces a discrete set of possible messages; each of the possible messages has a corresponding signal waveform. These signal waveforms are attenuated, or otherwise altered, by communications channel 103. To combat the noise channel 103, LDPC codes are utilized.

[22] By way of example, the channel 103 is a satellite link serving satellite terminals (e.g., Very Small Aperture Terminals (VSATs)) in support of broadband satellite applications. Such applications include satellite broadcasting and interactive services (and compliant with the Digital Video Broadcast (DVB) – S2 standard). The Digital Video Broadcasting via Satellite (DVB-S) standard has been widely adopted worldwide to provide, for instance, digital satellite television programming.

[23] The LDPC codes that are generated by the transmitter 101 enable high speed implementation without incurring any performance loss. These structured LDPC codes output from the transmitter 101 avoid assignment of a small number of check nodes to the bit nodes already vulnerable to channel errors by virtue of the modulation scheme (e.g., 8-PSK).

[24] Such LDPC codes have a parallelizable decoding algorithm (unlike turbo codes), which advantageously involves simple operations such as addition, comparison and table look-up. Moreover, carefully designed LDPC codes do not exhibit any sign of error floor.

[25] According to one embodiment of the present invention, the transmitter 101 generates, using a relatively simple encoding technique, LDPC codes based on parity check matrices (which facilitate efficient memory access during decoding) to communicate with the receiver 105. The transmitter 101 employs LDPC codes that can outperform concatenated turbo+RS (Reed-Solomon) codes, provided the block length is sufficiently large.

[26] FIGs. 2A and 2B are diagrams of exemplary LDPC encoders deployed in the transmitter of FIG. 1. As seen in FIG. 2A, a transmitter 200 is equipped with an LDPC encoder 203 that accepts input from an information source 201 and outputs coded stream of higher redundancy suitable for error correction processing at the receiver 105. The information source 201 generates k signals from a discrete alphabet, X . LDPC codes are specified with parity check matrices. On the other hand, encoding LDPC codes require, in general, specifying the generator matrices. Even though it is possible to obtain generator matrices from parity check matrices using Gaussian elimination, the resulting matrix is no longer sparse and storing a large generator matrix can be complex.

[27] The encoder 203 generates signals from alphabet Y to a modulator 205 using a simple encoding technique that makes use of only the parity check matrix by imposing structure onto the parity check matrix. Specifically, a restriction is placed on the parity check matrix by constraining certain portion of the matrix to be triangular. The construction of such a parity check matrix is described more fully below in FIG. 6. Such a restriction results in negligible performance loss, and therefore, constitutes an attractive trade-off.

[28] The modulator 205 maps the encoded messages from encoder 203 to signal waveforms that are transmitted to a transmit antenna 207, which emits these waveforms over the communication channel 103. Accordingly, the encoded messages are modulated and distributed to a transmit antenna 207. The transmissions from the transmit antenna 207 propagate to a receiver (shown in FIG. 3), as discussed below.

[29] FIG. 2B shows an LDPC encoder utilized with a Bose Chaudhuri Hocquenghem (BCH) encoder and a cyclic redundancy check (CRC) encoder, according to one embodiment of the present invention. Under this scenario, the codes generated by the LDPC encoder 203, along with the CRC encoder 209 and the BCH encoder 211, have a concatenated outer BCH code and inner low density parity check (LDPC) code. Furthermore, error detection is achieved using cyclic redundancy check (CRC) codes. The CRC encoder 209, in an

exemplary embodiment, encodes using an 8-bit CRC code with generator polynomial $(x^5+x^4+x^3+x^2+1)(x^2+x+1)(x+1)$. The CRC code is output to the BCH encoder 211.

[30] FIG. 2C provides a flowchart of the encoding process of the LDPC encoder of FIG. 2B for generating short frame length LDPC codes, according to one embodiment of the present invention. In step 211, information bits are received and processed to the chain of encoders 209, 211, and 203. Consequently, the LDPC encoder 203 generates LDPC codes with outer BCH codes based on the received information bits, as in step 223. The codes also contain the CRC code. Next, the LDPC codes are represented by signals that are modulated, per step 225, for transmission over the channel 103, which in an exemplary embodiment, is a satellite link to one or more satellite terminals (step 227).

[31] The LDPC encoder 203 systematically encodes an information block of size k_{ldpc} , $\mathbf{i} = (i_0, i_1, \dots, i_{k_{ldpc}-1})$ onto a codeword of size n_{ldpc} , $\mathbf{c} = (i_0, i_1, \dots, i_{k_{ldpc}-1}, p_0, p_1, \dots, p_{n_{ldpc}-k_{ldpc}-1})$. The transmission of the codeword starts in the given order from i_0 and ends with $p_{n_{ldpc}-k_{ldpc}-1}$. LDPC code parameters (n_{ldpc}, k_{ldpc}) .

[32] The task of the LDPC encoder 203 is to determine $n_{ldpc} - k_{ldpc}$ parity bits $(p_0, p_1, \dots, p_{n_{ldpc}-k_{ldpc}-1})$ for every block of k_{ldpc} information bits, $(i_0, i_1, \dots, i_{k_{ldpc}-1})$. The procedure is as follows. First, the parity bits are initialized;

$p_0 = p_1 = p_2 = \dots = p_{n_{ldpc}-k_{ldpc}-1} = 0$. The first information bit, i_0 , are accumulated at parity bit addresses specified in the first row of Tables 1-7. By way of example, k_{ldpc} bits are systematically encoded to generate n_{ldpc} bits. According to one embodiment of the present invention, n_{ldpc} is 16200 bits, which is a short block length. Given the relatively short length of such codes, LDPC codes having approximate lengths of 16200 bits or less are deemed "short" block length codes. According to one embodiment of the present invention, the parameters of the short frame length codes are provided in Table 8.

[33] After all of the information bits are exhausted, the final parity bits are obtained as follows. First, the following operations are performed, starting with $i = 1$

$$p_i = p_i \oplus p_{i-1}, \quad i = 1, 2, \dots, n_{ldpc} - k_{ldpc} - 1.$$

Final content of p_i , $i = 0, 1, \dots, n_{ldpc} - k_{ldpc} - 1$ is equal to the parity bit p_i .

Address of Parity Bit Accumulators (Shortened from Rate 1/2)									
20	712	2386	6354	4061	1062	5045	5158		
21	2543	5748	4822	2348	3089	6328	5876		
22	926	5701	269	3693	2438	3190	3507		
23	2802	4520	3577	5324	1091	4667	4449		
24	5140	2003	1263	4742	6497	1185	6202		
0	4046	6934							
1	2855	66							
2	6694	212							
3	3439	1158							
4	3850	4422							
5	5924	290							
6	1467	4049							
7	7820	2242							
8	4606	3080							
9	4633	7877							
10	3884	6868							
11	8935	4996							
12	3028	764							
13	5988	1057							
14	7411	3450							

Table 1

Address of Parity Bit Accumulators (Rate 3/5)															
2765	5713	6426	3596	1374	4811	2182	544	3394	2840	4310	771				
4951	211	2208	723	1246	2928	398	5739	265	5601	5993	2615				
210	4730	5777	3096	4282	6238	4939	1119	6463	5298	6320	4016				
4167	2063	4757	3157	5664	3956	6045	563	4284	2441	3412	6334				
4201	2428	4474	59	1721	736	2997	428	3807	1513	4732	6195				
2670	3081	5139	3736	1999	5889	4362	3806	4534	5409	6384	5809				
5516	1622	2906	3285	1257	5797	3816	817	875	2311	3543	1205				
4244	2184	5415	1705	5642	4886	2333	287	1848	1121	3595	6022				
2142	2830	4069	5654	1295	2951	3919	1356	884	1786	396	4738				
0	2161	2653													
1	1380	1461													
2	2502	3707													
3	3971	1057													
4	5985	6062													
5	1733	6028													
6	3786	1936													
7	4292	956													
8	5692	3417													
9	266	4878													
10	4913	3247													
11	4763	3937													
12	3590	2903													
13	2566	4215													
14	5208	4707													
15	3940	3388													
16	5109	4556													
17	4908	4177													

Table 2

Address of Parity Bit Accumulators (Rate 2/3)													
0	2084	1613	1548	1286	1460	3196	4297	2481	3369	3451	4620	2622	
1	122	1516	3448	2880	1407	1847	3799	3529	373	971	4358	3108	
2	259	3399	929	2650	864	3996	3833	107	5287	164	3125	2350	
3	342	3529											
4	4198	2147											
5	1880	4836											
6	3864	4910											
7	243	1542											
8	3011	1436											
9	2167	2512											
10	4606	1003											
11	2835	705											
12	3426	2365											
13	3848	2474											
14	1360	1743											
0	163	2536											
1	2583	1180											
2	1542	509											
3	4418	1005											
4	5212	5117											
5	2155	2922											
6	347	2696											
7	226	4296											
8	1560	487											
9	3926	1640											
10	149	2928											
11	2364	563											
12	635	688											
13	231	1684											
14	1129	3894											

Table 3

Address of Parity Bit Accumulators (Shortened from Rate 3/4)										
3	3198	478	4207	1481	1009	2616	1924	3437	554	683 1801
4	2681	2135								
5	3107	4027								
6	2637	3373								
7	3830	3449								
8	4129	2060								
9	4184	2742								
10	3946	1070								
11	2239	984								
0	1458	3031								
1	3003	1328								
2	1137	1716								
3	132	3725								
4	1817	638								
5	1774	3447								
6	3632	1257								
7	542	3694								
8	1015	1945								
9	1948	412								
10	995	2238								
11	4141	1907								
0	2480	3079								
1	3021	1088								
2	713	1379								
3	997	3903								
4	2323	3361								
5	1110	986								
6	2532	142								
7	1690	2405								
8	1298	1881								
9	615	174								
10	1648	3112								
11	1415	2808								

Table 4

Address of Parity Bit Accumulators (Shortened from Rate 4/5)	
5 896 1565	
6 2493 184	
7 212 3210	
8 727 1339	
9 3428 612	
0 2663 1947	
1 230 2695	
2 2025 2794	
3 3039 283	
4 862 2889	
5 376 2110	
6 2034 2286	
7 951 2068	
8 3108 3542	
9 307 1421	
0 2272 1197	
1 1800 3280	
2 331 2308	
3 465 2552	
4 1038 2479	
5 1383 343	
6 94 236	
7 2619 121	
8 1497 2774	
9 2116 1855	
0 722 1584	
1 2767 1881	
2 2701 1610	
3 3283 1732	
4 168 1099	
5 3074 243	
6 3460 945	
7 2049 1746	
8 566 1427	
9 3545 1168	

Table 5

Address of Parity Bit Accumulators (Shortened from Rate 5/6)												
3	2409	499	1481	908	559	716	1270	333	2508	2264	1702	2805
4	2447	1926										
5	414	1224										
6	2114	842										
7	212	573										
0	2383	2112										
1	2286	2348										
2	545	819										
3	1264	143										
4	1701	2258										
5	964	166										
6	114	2413										
7	2243	81										
0	1245	1581										
1	775	169										
2	1696	1104										
3	1914	2831										
4	532	1450										
5	91	974										
6	497	2228										
7	2326	1579										
0	2482	256										
1	1117	1261										
2	1257	1658										
3	1478	1225										
4	2511	980										
5	2320	2675										
6	435	1278										
7	228	503										
0	1885	2369										
1	57	483										
2	838	1050										
3	1231	1990										
4	1738	68										
5	2392	951										
6	163	645										
7	2644	1704										

Table 6

Address of Parity Bit Accumulators (Rate 8/9)	
0 1558 712 805	
1 1450 873 1337	
2 1741 1129 1184	
3 294 806 1566	
4 482 605 923	
0 926 1578	
1 777 1374	
2 608 151	
3 1195 210	
4 1484 692	
0 427 488	
1 828 1124	
2 874 1366	
3 1500 835	
4 1496 502	
0 1006 1701	
1 1155 97	
2 657 1403	
3 1453 624	
4 429 1495	
0 809 385	
1 367 151	
2 1323 202	
3 960 318	
4 1451 1039	
0 1098 1722	
1 1015 1428	
2 1261 1564	
3 544 1190	
4 1472 1246	
0 508 630	
1 421 1704	
2 284 898	
3 392 577	
4 1155 556	
0 631 1000	
1 732 1368	
2 1328 329	
3 1515 506	
4 1104 1172	

Table 7

[34] Tables 8-10 provide other exemplary code rates, 1/3, 1/5 and 2/5 for n_{ldpc} of 16200 bits:

Address of Parity Bit Accumulators (Rate 1/3)
416 8909 4156 3216 3112 2560 2912 6405 8593 4969 6723 6912
8978 3011 4339 9312 6396 2957 7288 5485 6031 10218 2226 3575
3383 10059 1114 10008 10147 9384 4290 434 5139 3536 1965 2291
2797 3693 7615 7077 743 1941 8716 6215 3840 5140 4582 5420
6110 8551 1515 7404 4879 4946 5383 1831 3441 9569 10472 4306
1505 5682 7778
7172 6830 6623
7281 3941 3505
10270 8669 914
3622 7563 9388
9930 5058 4554
4844 9609 2707
6883 3237 1714
4768 3878 10017
10127 3334 8267

Table 8

Address of Parity Bit Accumulators (Shortened from Rate 1/5)
6295 9626 304 7695 4839 4936 1660 144 11203 5567 6347 12557
10691 4988 3859 3734 3071 3494 7687 10313 5964 8069 8296 11090
10774 3613 5208 11177 7676 3549 8746 6583 7239 12265 2674 4292
11869 3708 5981 8718 4908 10650 6805 3334 2627 10461 9285 11120
7844 3079 10773
3385 10854 5747
1360 12010 12202
6189 4241 2343
9840 12726 4977

Table 9

Address of Parity Bit Accumulators (Rate 2/5)												
5650	4143	8750	583	6720	8071	635	1767	1344	6922	738	6658	
5696	1685	3207	415	7019	5023	5608	2605	857	6915	1770	8016	
3992	771	2190	7258	8970	7792	1802	1866	6137	8841	886	1931	
4108	3781	7577	6810	9322	8226	5396	5867	4428	8827	7766	2254	
4247	888	4367	8821	9660	324	5864	4774	227	7889	6405	8963	
9693	500	2520	2227	1811	9330	1928	5140	4030	4824	806	3134	
1652	8171	1435										
3366	6543	3745										
9286	8509	4645										
7397	5790	8972										
6597	4422	1799										
9276	4041	3847										
8683	7378	4946										
5348	1993	9186										
6724	9015	5646										
4502	4439	8474										
5107	7342	9442										
1387	8910	2660										

Table 10

[35] After all of the information bits are exhausted, the final parity bits are obtained as follows. First, the following operations are performed, starting with $i = 1$

$$p_i = p_i \oplus p_{i-1}, \quad i = 1, 2, \dots, n_{ldpc} - k_{ldpc} - 1.$$

Final content of p_i , $i = 0, 1, \dots, n_{ldpc} - k_{ldpc} - 1$ is equal to the parity bit p_i .

[36] As regards the BCH encoder 211, the BCH code parameters are enumerated in Table 11, with n_{ldpc} equal to 16200.

k_{ldpc}	k_{bch}	BCH Correction (bits)	Effective LDPC Rate k_{ldpc}/n_{ldpc}
7200	7032	12	0.444
9720	9552	12	3/5
10800	10632	12	2/3
11880	11712	12	0.733
12600	12432	12	0.777
13320	13152	12	0.822
14400	14232	12	8/9

Table 11

[37] The generator polynomial of the BCH code utilized by the BCH encoder 211 is as follows:

$$g(x) = (1+x+x^3+x^5+x^{14}) \times (1+x^6+x^8+x^{11}+x^{14}) \times (1+x+x^2+x^6+x^9+x^{10}+x^{14}) \times \\ (1+x^4+x^7+x^8+x^{10}+x^{12}+x^{14}) \times (1+x^2+x^4+x^6+x^8+x^9+x^{11}+x^{13}+x^{14}) \times \\ (1+x^3+x^7+x^8+x^9+x^{13}+x^{14}) \times (1+x^2+x^5+x^6+x^7+x^{10}+x^{11}+x^{13}+x^{14}) \times \\ (1+x^5+x^8+x^9+x^{10}+x^{11}+x^{14}) \times (1+x+x^2+x^3+x^9+x^{10}+x^{14}) \times (1+x^3+x^6+x^9+x^{11}+x^{12}+x^{14}) \times \\ (1+x^4+x^{11}+x^{12}+x^{14}) \times (1+x+x^2+x^3+x^5+x^6+x^7+x^8+x^{10}+x^{13}+x^{14}).$$

[38] BCH encoding of information bits $\mathbf{m} = (m_{k_{bch}-1}, m_{k_{bch}-2}, \dots, m_1, m_0)$ onto a codeword

$\mathbf{c} = (m_{k_{bch}-1}, m_{k_{bch}-2}, \dots, m_1, m_0, d_{n_{bch}-k_{bch}-1}, d_{n_{bch}-k_{bch}-2}, \dots, d_1, d_0)$ is achieved as follows. The message polynomial $m(x) = m_{k_{bch}-1}x^{k_{bch}-1} + m_{k_{bch}-2}x^{k_{bch}-2} + \dots + m_1x + m_0$ is multiplied by $x^{n_{bch}-k_{bch}}$. Next, $x^{n_{bch}-k_{bch}}m(x)$ divided by $g(x)$. With $d(x) = d_{n_{bch}-k_{bch}-1}x^{n_{bch}-k_{bch}-1} + \dots + d_1x + d_0$ as the remainder, the codeword polynomial is set as follows: $c(x) = x^{n_{bch}-k_{bch}}m(x) + d(x)$.

[39] As mentioned, the above LDPC codes, in an exemplary embodiment, can be used to variety of digital video applications, such as MPEG (Motion Pictures Expert Group) packet transmission.

[40] FIG. 3 is a diagram of an exemplary receiver in the system of FIG. 1. At the receiving side, a receiver 300 includes a demodulator 301 that performs demodulation of received signals from transmitter 200. These signals are received at a receive antenna 303 for demodulation. After demodulation, the received signals are forwarded to a decoder 305, which attempts to reconstruct the original source messages by generating messages, X' , in conjunction with a bit metric generator 307. The bit metric generator 307 may exchange information with the decoder 305 back and forth (iteratively) during the decoding process. These decoding approaches are more fully described in co-pending application, entitled "Method and System for Routing in Low Density Parity Check (LDPC) Decoders," filed July 3, 2003 (Publication No. US2004-0153960 A1). To appreciate the advantages offered by the present invention, it is instructive to examine how LDPC codes are generated, as discussed in FIG. 4.

[41] FIG. 4 is a diagram of a sparse parity check matrix, in accordance with an embodiment of the present invention. LDPC codes are long, linear block codes with sparse parity check matrix $H_{(n-k) \times n}$. Typically the block length, n , ranges from thousands to tens of

thousands of bits. For example, a parity check matrix for an LDPC code of length $n=8$ and rate $\frac{1}{2}$ is shown in FIG. 4. The same code can be equivalently represented by the bipartite graph, per FIG. 5.

[42] FIG. 5 is a diagram of a bipartite graph of an LDPC code of the matrix of FIG. 4.

Parity check equations imply that for each check node, the sum (over GF (Galois Field)(2)) of all adjacent bit nodes is equal to zero. As seen in the figure, bit nodes occupy the left side of the graph and are associated with one or more check nodes, according to a predetermined relationship. For example, corresponding to check node m_1 , the following expression exists $n_1 + n_4 + n_5 + n_8 = 0$ with respect to the bit nodes.

[43] Returning the receiver 303, the LDPC decoder 305 is considered a message passing decoder, whereby the decoder 305 aims to find the values of bit nodes. To accomplish this task, bit nodes and check nodes iteratively communicate with each other. The nature of this communication is described below.

[44] From check nodes to bit nodes, each check node provides to an adjacent bit node an estimate ("opinion") regarding the value of that bit node based on the information coming from other adjacent bit nodes. For instance, in the above example if the sum of n_4 , n_5 and n_8 "looks like" 0 to m_1 , then m_1 would indicate to n_1 that the value of n_1 is believed to be 0 (since $n_1 + n_4 + n_5 + n_8 = 0$); otherwise m_1 indicate to n_1 that the value of n_1 is believed to be 1. Additionally, for soft decision decoding, a reliability measure is added.

[45] From bit nodes to check nodes, each bit node relays to an adjacent check node an estimate about its own value based on the feedback coming from its other adjacent check nodes. In the above example n_1 has only two adjacent check nodes m_1 and m_3 . If the feedback coming from m_3 to n_1 indicates that the value of n_1 is probably 0, then n_1 would notify m_1 that an estimate of n_1 's own value is 0. For the case in which the bit node has more than two adjacent check nodes, the bit node performs a majority vote (soft decision) on the feedback coming from its other adjacent check nodes before reporting that decision to the check node it communicates. The above process is repeated until all bit nodes are considered to be correct (i.e., all parity check equations are satisfied) or until a predetermined maximum number of iterations is reached, whereby a decoding failure is declared.

[46] FIG. 6 is a diagram of a sub-matrix of a sparse parity check matrix, wherein the sub-matrix contains parity check values restricted to the lower triangular region, according to an embodiment of the present invention. As described previously, the encoder 203 (of FIGs. 2A and 2B) can employ a simple encoding technique by restricting the values of the lower triangular area of the parity check matrix. According to an embodiment of the present invention, the restriction imposed on the parity check matrix is of the form:

$$H_{(n-k) \times n} = [A_{(n-k) \times k} B_{(n-k) \times (n-k)}]$$

, where B is lower triangular.

[47] Any information block $i = (i_0, i_1, \dots, i_{k-1})$ is encoded to a codeword

$c = (i_0, i_1, \dots, i_{k-1}, p_0, p_1, \dots, p_{n-k-1})$ using $Hc^T = 0$, and recursively solving for parity bits; for example,

$$a_{00}i_0 + a_{01}i_1 + \dots + a_{0,k-1}i_{k-1} + p_0 = 0 \Rightarrow \text{Solve } p_0,$$

$$a_{10}i_0 + a_{11}i_1 + \dots + a_{1,k-1}i_{k-1} + b_{10}p_0 + p_1 = 0 \Rightarrow \text{Solve } p_1$$

and similarly for $p_2, p_3, \dots, p_{n-k-1}$.

[48] FIG. 7 illustrates a computer system upon which an embodiment according to the present invention can be implemented. The computer system 700 includes a bus 701 or other communication mechanism for communicating information, and a processor 703 coupled to the bus 701 for processing information. The computer system 700 also includes main memory 705, such as a random access memory (RAM) or other dynamic storage device, coupled to the bus 701 for storing information and instructions to be executed by the processor 703. Main memory 705 can also be used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor 703. The computer system 700 further includes a read only memory (ROM) 707 or other static storage device coupled to the bus 701 for storing static information and instructions for the processor 703. A storage device 709, such as a magnetic disk or optical disk, is additionally coupled to the bus 701 for storing information and instructions.

[49] The computer system 700 may be coupled via the bus 701 to a display 711, such as a cathode ray tube (CRT), liquid crystal display, active matrix display, or plasma display, for displaying information to a computer user. An input device 713, such as a keyboard including alphanumeric and other keys, is coupled to the bus 701 for communicating

information and command selections to the processor 703. Another type of user input device is cursor control 715, such as a mouse, a trackball, or cursor direction keys for communicating direction information and command selections to the processor 703 and for controlling cursor movement on the display 711.

[50] According to one embodiment of the invention, generation of LDPC codes is provided by the computer system 700 in response to the processor 703 executing an arrangement of instructions contained in main memory 705. Such instructions can be read into main memory 705 from another computer-readable medium, such as the storage device 709. Execution of the arrangement of instructions contained in main memory 705 causes the processor 703 to perform the process steps described herein. One or more processors in a multi-processing arrangement may also be employed to execute the instructions contained in main memory 705. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions to implement the embodiment of the present invention. Thus, embodiments of the present invention are not limited to any specific combination of hardware circuitry and software.

[51] The computer system 700 also includes a communication interface 717 coupled to bus 701. The communication interface 717 provides a two-way data communication coupling to a network link 719 connected to a local network 721. For example, the communication interface 717 may be a digital subscriber line (DSL) card or modem, an integrated services digital network (ISDN) card, a cable modem, or a telephone modem to provide a data communication connection to a corresponding type of telephone line. As another example, communication interface 717 may be a local area network (LAN) card (e.g. for Ethernet™ or an Asynchronous Transfer Model (ATM) network) to provide a data communication connection to a compatible LAN. Wireless links can also be implemented. In any such implementation, communication interface 717 sends and receives electrical, electromagnetic, or optical signals that carry digital data streams representing various types of information. Further, the communication interface 717 can include peripheral interface devices, such as a Universal Serial Bus (USB) interface, a PCMCIA (Personal Computer Memory Card International Association) interface, etc.

[52] The network link 719 typically provides data communication through one or more networks to other data devices. For example, the network link 719 may provide a connection

through local network 721 to a host computer 723, which has connectivity to a network 725 (e.g. a wide area network (WAN) or the global packet data communication network now commonly referred to as the "Internet") or to data equipment operated by service provider. The local network 721 and network 725 both use electrical, electromagnetic, or optical signals to convey information and instructions. The signals through the various networks and the signals on network link 719 and through communication interface 717, which communicate digital data with computer system 700, are exemplary forms of carrier waves bearing the information and instructions.

[53] The computer system 700 can send messages and receive data, including program code, through the network(s), network link 719, and communication interface 717. In the Internet example, a server (not shown) might transmit requested code belonging to an application program for implementing an embodiment of the present invention through the network 725, local network 721 and communication interface 717. The processor 703 may execute the transmitted code while being received and/or store the code in storage device 79, or other non-volatile storage for later execution. In this manner, computer system 700 may obtain application code in the form of a carrier wave.

[54] The term "computer-readable medium" as used herein refers to any medium that participates in providing instructions to the processor 703 for execution. Such a medium may take many forms, including but not limited to non-volatile media, volatile media, and transmission media. Non-volatile media include, for example, optical or magnetic disks, such as storage device 709. Volatile media include dynamic memory, such as main memory 705. Transmission media include coaxial cables, copper wire and fiber optics, including the wires that comprise bus 701. Transmission media can also take the form of acoustic, optical, or electromagnetic waves, such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, CDRW, DVD, any other optical medium, punch cards, paper tape, optical mark sheets, any other physical medium with patterns of holes or other optically recognizable indicia, a RAM, a PROM, and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave, or any other medium from which a computer can read.

[55] Various forms of computer-readable media may be involved in providing instructions to a processor for execution. For example, the instructions for carrying out at least part of the present invention may initially be borne on a magnetic disk of a remote computer. In such a scenario, the remote computer loads the instructions into main memory and sends the instructions over a telephone line using a modem. A modem of a local computer system receives the data on the telephone line and uses an infrared transmitter to convert the data to an infrared signal and transmit the infrared signal to a portable computing device, such as a personal digital assistance (PDA) and a laptop. An infrared detector on the portable computing device receives the information and instructions borne by the infrared signal and places the data on a bus. The bus conveys the data to main memory, from which a processor retrieves and executes the instructions. The instructions received by main memory may optionally be stored on storage device either before or after execution by processor.

[56] Accordingly, the various embodiments of the present invention provide an approach for encoding short block length Low Density Parity Check (LDPC) codes. An encoder generates a LDPC code having an outer Bose Chaudhuri Hocquenghem (BCH) code according to one of Tables 1-10 for transmission as the LDPC coded signal. Each of the Tables 1-10 specifies the address of parity bit accumulators. Structure is imposed on the LDPC codes by restricting portion part of the parity check matrix to be lower triangular and/or satisfying other requirements such that the communication between bit nodes and check nodes of the decoder is simplified. Further, a cyclic redundancy check (CRC) encoder is supplied to encode the input signal according to a CRC code. The above approach advantageously yields reduced complexity without sacrificing performance.

[57] While the present invention has been described in connection with a number of embodiments and implementations, the present invention is not so limited but covers various obvious modifications and equivalent arrangements, which fall within the purview of the appended claims.

We Claim:

1. A method comprising:

decoding an encoded signal that was encoded according to a Low Density Parity Check

(LDPC) code by accumulating bits at parity bit addresses as specified by any one of

Tables 1-10 for transmission as an LDPC coded signal, wherein parity bits, p_i , are

determined according to $p_i = p_i \oplus p_{i-1}$, $i = 1, 2, \dots, n_{ldpc} - k_{ldpc} - 1$, k_{ldpc} being

information block size and n_{ldpc} being codeword size:

Address of Parity Bit Accumulators (Shortened from Rate 1/2)	
20	712 2386 6354 4061 1062 5045 5158
21	2543 5748 4822 2348 3089 6328 5876
22	926 5701 269 3693 2438 3190 3507
23	2802 4520 3577 5324 1091 4667 4449
24	5140 2003 1263 4742 6497 1185 6202
0	4046 6934
1	2855 66
2	6694 212
3	3439 1158
4	3850 4422
5	5924 290
6	1467 4049
7	7820 2242
8	4606 3080
9	4633 7877
10	3884 6868
11	8935 4996
12	3028 764
13	5988 1057
14	7411 3450

Table 1

Address of Parity Bit Accumulators (Rate 3/5)															
2765	5713	6426	3596	1374	4811	2182	544	3394	2840	4310	771				
4951	211	2208	723	1246	2928	398	5739	265	5601	5993	2615				
210	4730	5777	3096	4282	6238	4939	1119	6463	5298	6320	4016				
4167	2063	4757	3157	5664	3956	6045	563	4284	2441	3412	6334				
4201	2428	4474	59	1721	736	2997	428	3807	1513	4732	6195				
2670	3081	5139	3736	1999	5889	4362	3806	4534	5409	6384	5809				
5516	1622	2906	3285	1257	5797	3816	817	875	2311	3543	1205				
4244	2184	5415	1705	5642	4886	2333	287	1848	1121	3595	6022				
2142	2830	4069	5654	1295	2951	3919	1356	884	1786	396	4738				
0	2161	2653													
1	1380	1461													
2	2502	3707													
3	3971	1057													
4	5985	6062													
5	1733	6028													
6	3786	1936													
7	4292	956													
8	5692	3417													
9	266	4878													
10	4913	3247													
11	4763	3937													
12	3590	2903													
13	2566	4215													
14	5208	4707													
15	3940	3388													
16	5109	4556													
17	4908	4177													

Table 2

Address of Parity Bit Accumulators (Rate 2/3)												
0	2084	1613	1548	1286	1460	3196	4297	2481	3369	3451	4620	2622
1	122	1516	3448	2880	1407	1847	3799	3529	373	971	4358	3108
2	259	3399	929	2650	864	3996	3833	107	5287	164	3125	2350
3	342	3529										
4	4198	2147										
5	1880	4836										
6	3864	4910										
7	243	1542										
8	3011	1436										
9	2167	2512										
10	4606	1003										
11	2835	705										
12	3426	2365										
13	3848	2474										
14	1360	1743										
0	163	2536										
1	2583	1180										
2	1542	509										
3	4418	1005										
4	5212	5117										
5	2155	2922										
6	347	2696										
7	226	4296										
8	1560	487										
9	3926	1640										
10	149	2928										
11	2364	563										
12	635	688										
13	231	1684										
14	1129	3894										

Table 3

Address of Parity Bit Accumulators (Shortened from Rate 3/4)									
3	3198	478	4207	1481	1009	2616	1924	3437	554 683 1801
4	2681	2135							
5	3107	4027							
6	2637	3373							
7	3830	3449							
8	4129	2060							
9	4184	2742							
10	3946	1070							
11	2239	984							
0	1458	3031							
1	3003	1328							
2	1137	1716							
3	132	3725							
4	1817	638							
5	1774	3447							
6	3632	1257							
7	542	3694							
8	1015	1945							
9	1948	412							
10	995	2238							
11	4141	1907							
0	2480	3079							
1	3021	1088							
2	713	1379							
3	997	3903							
4	2323	3361							
5	1110	986							
6	2532	142							
7	1690	2405							
8	1298	1881							
9	615	174							
10	1648	3112							
11	1415	2808							

Table 4

Address of Parity Bit Accumulators (Shortened from Rate 4/5)	
5 896 1565	
6 2493 184	
7 212 3210	
8 727 1339	
9 3428 612	
0 2663 1947	
1 230 2695	
2 2025 2794	
3 3039 283	
4 862 2889	
5 376 2110	
6 2034 2286	
7 951 2068	
8 3108 3542	
9 307 1421	
0 2272 1197	
1 1800 3280	
2 331 2308	
3 465 2552	
4 1038 2479	
5 1383 343	
6 94 236	
7 2619 121	
8 1497 2774	
9 2116 1855	
0 722 1584	
1 2767 1881	
2 2701 1610	
3 3283 1732	
4 168 1099	
5 3074 243	
6 3460 945	
7 2049 1746	
8 566 1427	
9 3545 1168	

Table 5

Address of Parity Bit Accumulators (Shortened from Rate 5/6)	
3 2409 499 1481 908 559 716 1270 333 2508 2264 1702 2805	
4 2447 1926	
5 414 1224	
6 2114 842	
7 212 573	
0 2383 2112	
1 2286 2348	
2 545 819	
3 1264 143	
4 1701 2258	
5 964 166	
6 114 2413	
7 2243 81	
0 1245 1581	
1 775 169	
2 1696 1104	
3 1914 2831	
4 532 1450	
5 91 974	
6 497 2228	
7 2326 1579	
0 2482 256	
1 1117 1261	
2 1257 1658	
3 1478 1225	
4 2511 980	
5 2320 2675	
6 435 1278	
7 228 503	
0 1885 2369	
1 57 483	
2 838 1050	
3 1231 1990	
4 1738 68	
5 2392 951	
6 163 645	
7 2644 1704	

Table 6

Address of Parity Bit Accumulators (Rate 8/9)	
0 1558 712 805	
1 1450 873 1337	
2 1741 1129 1184	
3 294 806 1566	
4 482 605 923	
0 926 1578	
1 777 1374	
2 608 151	
3 1195 210	
4 1484 692	
0 427 488	
1 828 1124	
2 874 1366	
3 1500 835	
4 1496 502	
0 1006 1701	
1 1155 97	
2 657 1403	
3 1453 624	
4 429 1495	
0 809 385	
1 367 151	
2 1323 202	
3 960 318	
4 1451 1039	
0 1098 1722	
1 1015 1428	
2 1261 1564	
3 544 1190	
4 1472 1246	
0 508 630	
1 421 1704	
2 284 898	
3 392 577	
4 1155 556	
0 631 1000	
1 732 1368	
2 1328 329	
3 1515 506	
4 1104 1172	

Table 7

Address of Parity Bit Accumulators (Rate 1/3)												
416	8909	4156	3216	3112	2560	2912	6405	8593	4969	6723	6912	
8978	3011	4339	9312	6396	2957	7288	5485	6031	10218	2226	3575	
3383	10059	1114	10008	10147	9384	4290	434	5139	3536	1965	2291	
2797	3693	7615	7077	743	1941	8716	6215	3840	5140	4582	5420	
6110	8551	1515	7404	4879	4946	5383	1831	3441	9569	10472	4306	
1505	5682	7778										
7172	6830	6623										
7281	3941	3505										
10270	8669	914										
3622	7563	9388										
9930	5058	4554										
4844	9609	2707										
6883	3237	1714										
4768	3878	10017										
10127	3334	8267										

Table 8

Address of Parity Bit Accumulators (Shortened from Rate 1/4)												
6295	9626	304	7695	4839	4936	1660	144	11203	5567	6347	12557	
10691	4988	3859	3734	3071	3494	7687	10313	5964	8069	8296	11090	
10774	3613	5208	11177	7676	3549	8746	6583	7239	12265	2674	4292	
11869	3708	5981	8718	4908	10650	6805	3334	2627	10461	9285	11120	
7844	3079	10773										
3385	10854	5747										
1360	12010	12202										
6189	4241	2343										
9840	12726	4977										

Table 9

Address of Parity Bit Accumulators (Rate 2/5)														
5650	4143	8750	583	6720	8071	635	1767	1344	6922	738	6658			
5696	1685	3207	415	7019	5023	5608	2605	857	6915	1770	8016			
3992	771	2190	7258	8970	7792	1802	1866	6137	8841	886	1931			
4108	3781	7577	6810	9322	8226	5396	5867	4428	8827	7766	2254			
4247	888	4367	8821	9660	324	5864	4774	227	7889	6405	8963			
9693	500	2520	2227	1811	9330	1928	5140	4030	4824	806	3134			
1652	8171	1435												
3366	6543	3745												
9286	8509	4645												
7397	5790	8972												
6597	4422	1799												
9276	4041	3847												
8683	7378	4946												
5348	1993	9186												
6724	9015	5646												
4502	4439	8474												
5107	7342	9442												
1387	8910	2660												

Table 10.

2. A method according to claim 1, wherein the encoded signal includes a Bose Chaudhuri

Hocquenghem (BCH) outer code that is based on a generator polynomial of:

$$\begin{aligned}
 g(x) = & (1+x+x^3+x^5+x^{14}) \times (1+x^6+x^8+x^{11}+x^{14}) \times (1+x+x^2+x^6+x^9+x^{10}+x^{14}) \times \\
 & (1+x^4+x^7+x^8+x^{10}+x^{12}+x^{14}) \times (1+x^2+x^4+x^6+x^8+x^9+x^{11}+x^{13}+x^{14}) \times \\
 & (1+x^3+x^7+x^8+x^9+x^{13}+x^{14}) \times (1+x^2+x^5+x^6+x^7+x^{10}+x^{11}+x^{13}+x^{14}) \times \\
 & (1+x^5+x^8+x^9+x^{10}+x^{11}+x^{14}) \times (1+x+x^2+x^3+x^9+x^{10}+x^{14}) \times (1+x^3+x^6+x^9+x^{11}+x^{12}+x^{14}) \times \\
 & (1+x^4+x^{11}+x^{12}+x^{14}) \times (1+x+x^2+x^3+x^5+x^6+x^7+x^8+x^{10}+x^{13}+x^{14}).
 \end{aligned}$$

3. A method according to claim 1, wherein n_{ldpc} equals to 16200, and a Bose Chaudhuri

Hocquenghem (BCH) outer code is applied to the LDPC code according to Table 11 to output

a coded signal:

k_{ldpc}	k_{bch}	BCH Correction (bits)	Effective LDPC Rate k_{ldpc}/n_{ldpc}
7200	7032	12	0.444
9720	9552	12	3/5
10800	10632	12	2/3
11880	11712	12	0.733
12600	12432	12	0.777
13320	13152	12	0.822
14400	14232	12	8/9

Table 11.

4. A method according to claim 3, wherein the coded signal is utilized in a digital video application.
5. A method according to claim 4, wherein the video application conforms with MPEG (Motion Pictures Expert Group) packet transmission.
6. A method according to claim 1, further comprising:
 computing a cyclic redundancy check (CRC) based on a generator polynomial of
 $(x^5+x^4+x^3+x^2+1)(x^2+x+1)(x+1)$.
7. A computer-readable storage medium bearing instructions for decoding a Low Density Parity Check (LDPC) coded signal, wherein said instructions are arranged, upon execution, to cause one or more processors to perform the method of any one of claims 1 to 6.
8. A receiver configured to receive the encoded signal in accordance with any one of claims 1 to 6.

9. An apparatus comprising:

circuitry configured to decode an encoded signal that was encoded according to a Low

Density Parity Check (LDPC) code by accumulating bits at parity bit addresses as

specified by any one of Tables 1-10 for transmission as an LDPC coded signal,

wherein parity bits, p_i , are determined according to

$$p_i = p_i \oplus p_{i-1}, \quad i = 1, 2, \dots, n_{ldpc} - k_{ldpc} - 1, \quad k_{ldpc} \text{ being information block size and } n_{ldpc}$$

being codeword size:

Address of Parity Bit Accumulators (Shortened from Rate 1/2)									
20	712	2386	6354	4061	1062	5045	5158		
21	2543	5748	4822	2348	3089	6328	5876		
22	926	5701	269	3693	2438	3190	3507		
23	2802	4520	3577	5324	1091	4667	4449		
24	5140	2003	1263	4742	6497	1185	6202		
0	4046	6934							
1	2855	66							
2	6694	212							
3	3439	1158							
4	3850	4422							
5	5924	290							
6	1467	4049							
7	7820	2242							
8	4606	3080							
9	4633	7877							
10	3884	6868							
11	8935	4996							
12	3028	764							
13	5988	1057							
14	7411	3450							

Table 1

Address of Parity Bit Accumulators (Rate 3/5)															
2765	5713	6426	3596	1374	4811	2182	544	3394	2840	4310	771				
4951	211	2208	723	1246	2928	398	5739	265	5601	5993	2615				
210	4730	5777	3096	4282	6238	4939	1119	6463	5298	6320	4016				
4167	2063	4757	3157	5664	3956	6045	563	4284	2441	3412	6334				
4201	2428	4474	59	1721	736	2997	428	3807	1513	4732	6195				
2670	3081	5139	3736	1999	5889	4362	3806	4534	5409	6384	5809				
5516	1622	2906	3285	1257	5797	3816	817	875	2311	3543	1205				
4244	2184	5415	1705	5642	4886	2333	287	1848	1121	3595	6022				
2142	2830	4069	5654	1295	2951	3919	1356	884	1786	396	4738				
0	2161	2653													
1	1380	1461													
2	2502	3707													
3	3971	1057													
4	5985	6062													
5	1733	6028													
6	3786	1936													
7	4292	956													
8	5692	3417													
9	266	4878													
10	4913	3247													
11	4763	3937													
12	3590	2903													
13	2566	4215													
14	5208	4707													
15	3940	3388													
16	5109	4556													
17	4908	4177													

Table 2

Address of Parity Bit Accumulators (Rate 2/3)												
0	2084	1613	1548	1286	1460	3196	4297	2481	3369	3451	4620	2622
1	122	1516	3448	2880	1407	1847	3799	3529	373	971	4358	3108
2	259	3399	929	2650	864	3996	3833	107	5287	164	3125	2350
3	342	3529										
4	4198	2147										
5	1880	4836										
6	3864	4910										
7	243	1542										
8	3011	1436										
9	2167	2512										
10	4606	1003										
11	2835	705										
12	3426	2365										
13	3848	2474										
14	1360	1743										
0	163	2536										
1	2583	1180										
2	1542	509										
3	4418	1005										
4	5212	5117										
5	2155	2922										
6	347	2696										
7	226	4296										
8	1560	487										
9	3926	1640										
10	149	2928										
11	2364	563										
12	635	688										
13	231	1684										
14	1129	3894										

Table 3

Address of Parity Bit Accumulators (Shortened from Rate 3/4)										
3	3198	478	4207	1481	1009	2616	1924	3437	554	683 1801
4	2681	2135								
5	3107	4027								
6	2637	3373								
7	3830	3449								
8	4129	2060								
9	4184	2742								
10	3946	1070								
11	2239	984								
0	1458	3031								
1	3003	1328								
2	1137	1716								
3	132	3725								
4	1817	638								
5	1774	3447								
6	3632	1257								
7	542	3694								
8	1015	1945								
9	1948	412								
10	995	2238								
11	4141	1907								
0	2480	3079								
1	3021	1088								
2	713	1379								
3	997	3903								
4	2323	3361								
5	1110	986								
6	2532	142								
7	1690	2405								
8	1298	1881								
9	615	174								
10	1648	3112								
11	1415	2808								

Table 4

Address of Parity Bit Accumulators (Shortened from Rate 4/5)	
5 896 1565	
6 2493 184	
7 212 3210	
8 727 1339	
9 3428 612	
0 2663 1947	
1 230 2695	
2 2025 2794	
3 3039 283	
4 862 2889	
5 376 2110	
6 2034 2286	
7 951 2068	
8 3108 3542	
9 307 1421	
0 2272 1197	
1 1800 3280	
2 331 2308	
3 465 2552	
4 1038 2479	
5 1383 343	
6 94 236	
7 2619 121	
8 1497 2774	
9 2116 1855	
0 722 1584	
1 2767 1881	
2 2701 1610	
3 3283 1732	
4 168 1099	
5 3074 243	
6 3460 945	
7 2049 1746	
8 566 1427	
9 3545 1168	

Table 5

Address of Parity Bit Accumulators (Shortened from Rate 5/6)	
3 2409 499 1481 908 559 716 1270 333 2508 2264 1702 2805	
4 2447 1926	
5 414 1224	
6 2114 842	
7 212 573	
0 2383 2112	
1 2286 2348	
2 545 819	
3 1264 143	
4 1701 2258	
5 964 166	
6 114 2413	
7 2243 81	
0 1245 1581	
1 775 169	
2 1696 1104	
3 1914 2831	
4 532 1450	
5 91 974	
6 497 2228	
7 2326 1579	
0 2482 256	
1 1117 1261	
2 1257 1658	
3 1478 1225	
4 2511 980	
5 2320 2675	
6 435 1278	
7 228 503	
0 1885 2369	
1 57 483	
2 838 1050	
3 1231 1990	
4 1738 68	
5 2392 951	
6 163 645	
7 2644 1704	

Table 6

Address of Parity Bit Accumulators (Rate 8/9)	
0 1558 712 805	
1 1450 873 1337	
2 1741 1129 1184	
3 294 806 1566	
4 482 605 923	
0 926 1578	
1 777 1374	
2 608 151	
3 1195 210	
4 1484 692	
0 427 488	
1 828 1124	
2 874 1366	
3 1500 835	
4 1496 502	
0 1006 1701	
1 1155 97	
2 657 1403	
3 1453 624	
4 429 1495	
0 809 385	
1 367 151	
2 1323 202	
3 960 318	
4 1451 1039	
0 1098 1722	
1 1015 1428	
2 1261 1564	
3 544 1190	
4 1472 1246	
0 508 630	
1 421 1704	
2 284 898	
3 392 577	
4 1155 556	
0 631 1000	
1 732 1368	
2 1328 329	
3 1515 506	
4 1104 1172	

Table 7

Address of Parity Bit Accumulators (Rate 1/3)												
416	8909	4156	3216	3112	2560	2912	6405	8593	4969	6723	6912	
8978	3011	4339	9312	6396	2957	7288	5485	6031	10218	2226	3575	
3383	10059	1114	10008	10147	9384	4290	434	5139	3536	1965	2291	
2797	3693	7615	7077	743	1941	8716	6215	3840	5140	4582	5420	
6110	8551	1515	7404	4879	4946	5383	1831	3441	9569	10472	4306	
1505	5682	7778										
7172	6830	6623										
7281	3941	3505										
10270	8669	914										
3622	7563	9388										
9930	5058	4554										
4844	9609	2707										
6883	3237	1714										
4768	3878	10017										
10127	3334	8267										

Table 8

Address of Parity Bit Accumulators (Shortened from Rate 1/4)												
6295	9626	304	7695	4839	4936	1660	144	11203	5567	6347	12557	
10691	4988	3859	3734	3071	3494	7687	10313	5964	8069	8296	11090	
10774	3613	5208	11177	7676	3549	8746	6583	7239	12265	2674	4292	
11869	3708	5981	8718	4908	10650	6805	3334	2627	10461	9285	11120	
7844	3079	10773										
3385	10854	5747										
1360	12010	12202										
6189	4241	2343										
9840	12726	4977										

Table 9

Address of Parity Bit Accumulators (Rate 2/5)															
5650	4143	8750	583	6720	8071	635	1767	1344	6922	738	6658				
5696	1685	3207	415	7019	5023	5608	2605	857	6915	1770	8016				
3992	771	2190	7258	8970	7792	1802	1866	6137	8841	886	1931				
4108	3781	7577	6810	9322	8226	5396	5867	4428	8827	7766	2254				
4247	888	4367	8821	9660	324	5864	4774	227	7889	6405	8963				
9693	500	2520	2227	1811	9330	1928	5140	4030	4824	806	3134				
1652	8171	1435													
3366	6543	3745													
9286	8509	4645													
7397	5790	8972													
6597	4422	1799													
9276	4041	3847													
8683	7378	4946													
5348	1993	9186													
6724	9015	5646													
4502	4439	8474													
5107	7342	9442													
1387	8910	2660													

Table 10.

10. An apparatus according to claim 9, wherein the encoded signal includes a Bose

Chaudhuri Hocquenghem (BCH) outer code that is based on a generator polynomial of:

$$\begin{aligned}
 g(x) = & (1+x+x^3+x^5+x^{14}) \times (1+x^6+x^8+x^{11}+x^{14}) \times (1+x+x^2+x^6+x^9+x^{10}+x^{14}) \times \\
 & (1+x^4+x^7+x^8+x^{10}+x^{12}+x^{14}) \times (1+x^2+x^4+x^6+x^8+x^9+x^{11}+x^{13}+x^{14}) \times \\
 & (1+x^3+x^7+x^8+x^9+x^{13}+x^{14}) \times (1+x^2+x^5+x^6+x^7+x^{10}+x^{11}+x^{13}+x^{14}) \times \\
 & (1+x^5+x^8+x^9+x^{10}+x^{11}+x^{14}) \times (1+x+x^2+x^3+x^9+x^{10}+x^{14}) \times (1+x^3+x^6+x^9+x^{11}+x^{12}+x^{14}) \times \\
 & (1+x^4+x^{11}+x^{12}+x^{14}) \times (1+x+x^2+x^3+x^5+x^6+x^7+x^8+x^{10}+x^{13}+x^{14}).
 \end{aligned}$$

11. An apparatus according to claim 9, wherein n_{ldpc} equals to 16200, and a Bose

Chaudhuri Hocquenghem (BCH) outer code is applied to the LDPC code according to Table

11 to output a coded signal:

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k_{ldpc}	k_{bch}	BCH Correction (bits)	Effective LDPC Rate k_{ldpc}/n_{ldpc}
7200	7032	12	0.444
9720	9552	12	3/5
10800	10632	12	2/3
11880	11712	12	0.733
12600	12432	12	0.777
13320	13152	12	0.822
14400	14232	12	8/9

Table 11.

12. An apparatus according to claim 11, wherein the coded signal is utilized in a digital video application.

13. An apparatus according to claim 12, wherein the video application conforms with MPEG (Motion Pictures Expert Group) packet transmission.

14. An apparatus according to claim 9, wherein the circuitry is further configured to compute a cyclic redundancy check (CRC) based on a generator polynomial of $(x^5+x^4+x^3+x^2+1)(x^2+x+1)(x+1)$.

FIG. 1

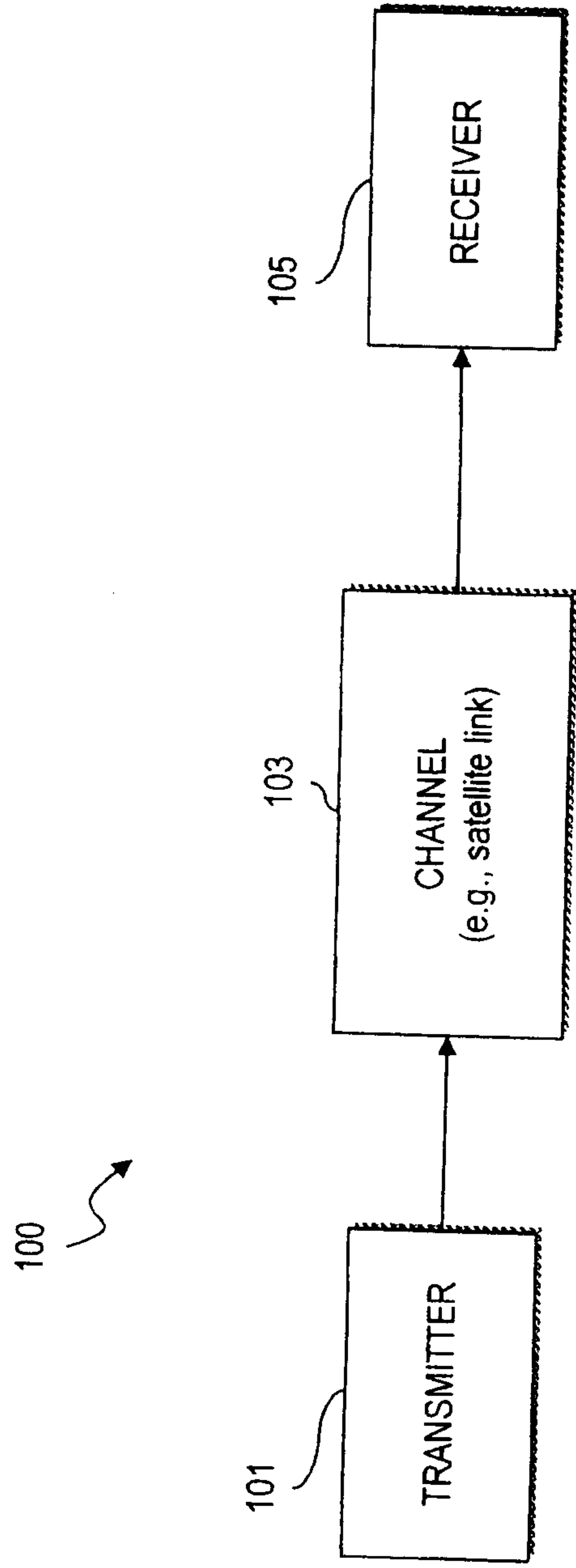


FIG. 2A

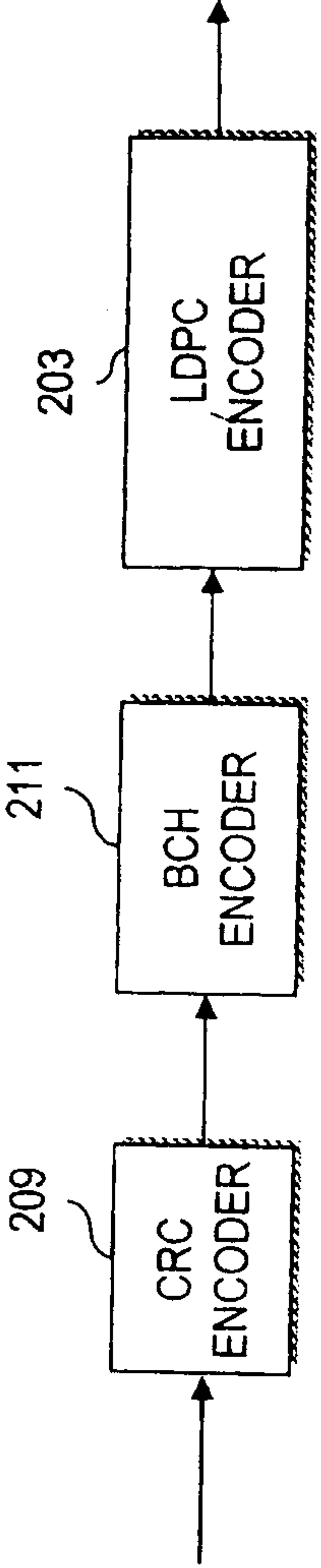
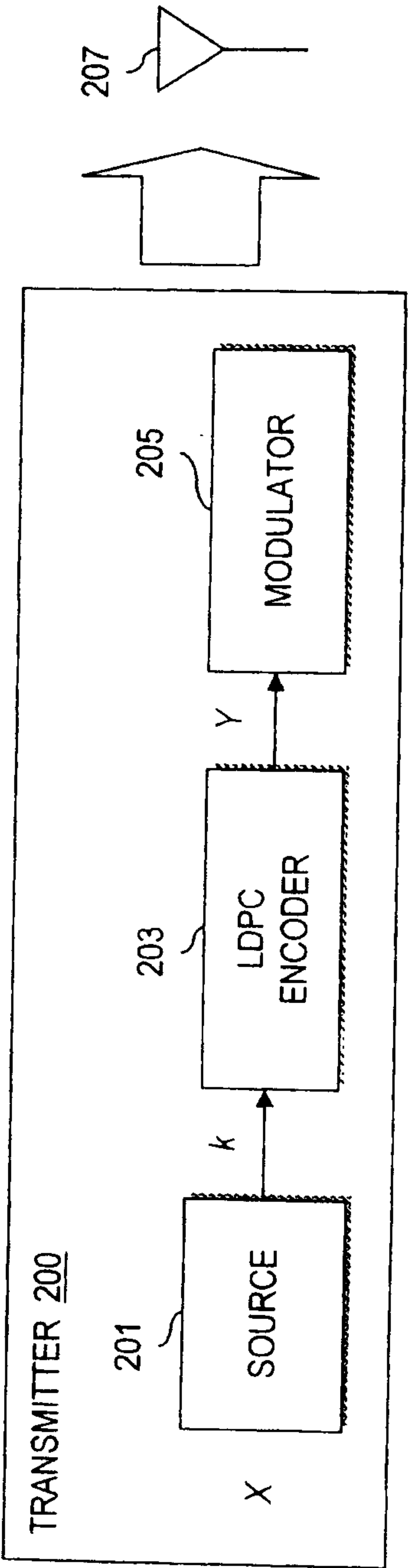


FIG. 2B

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FIG. 2C

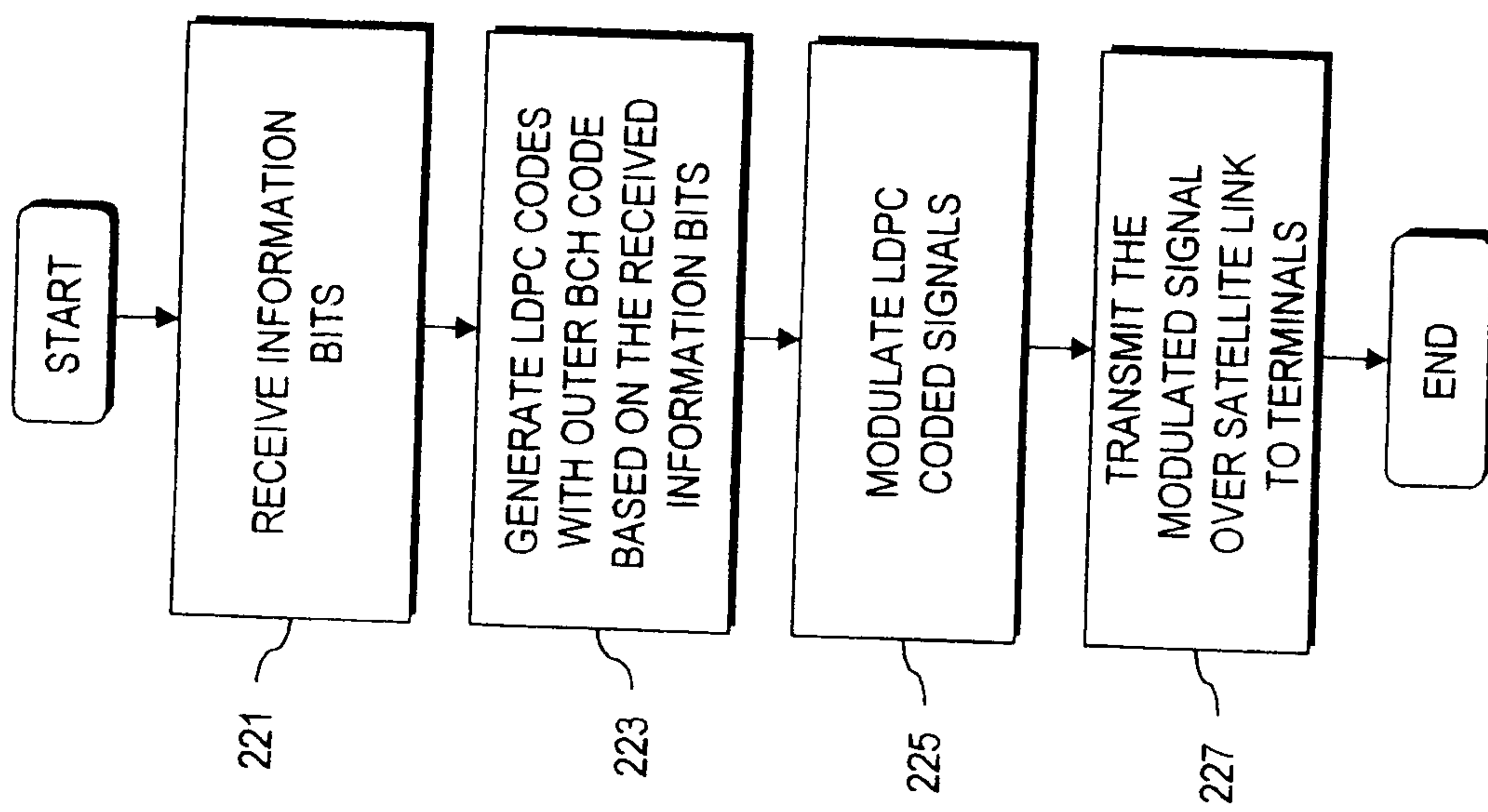


FIG. 3

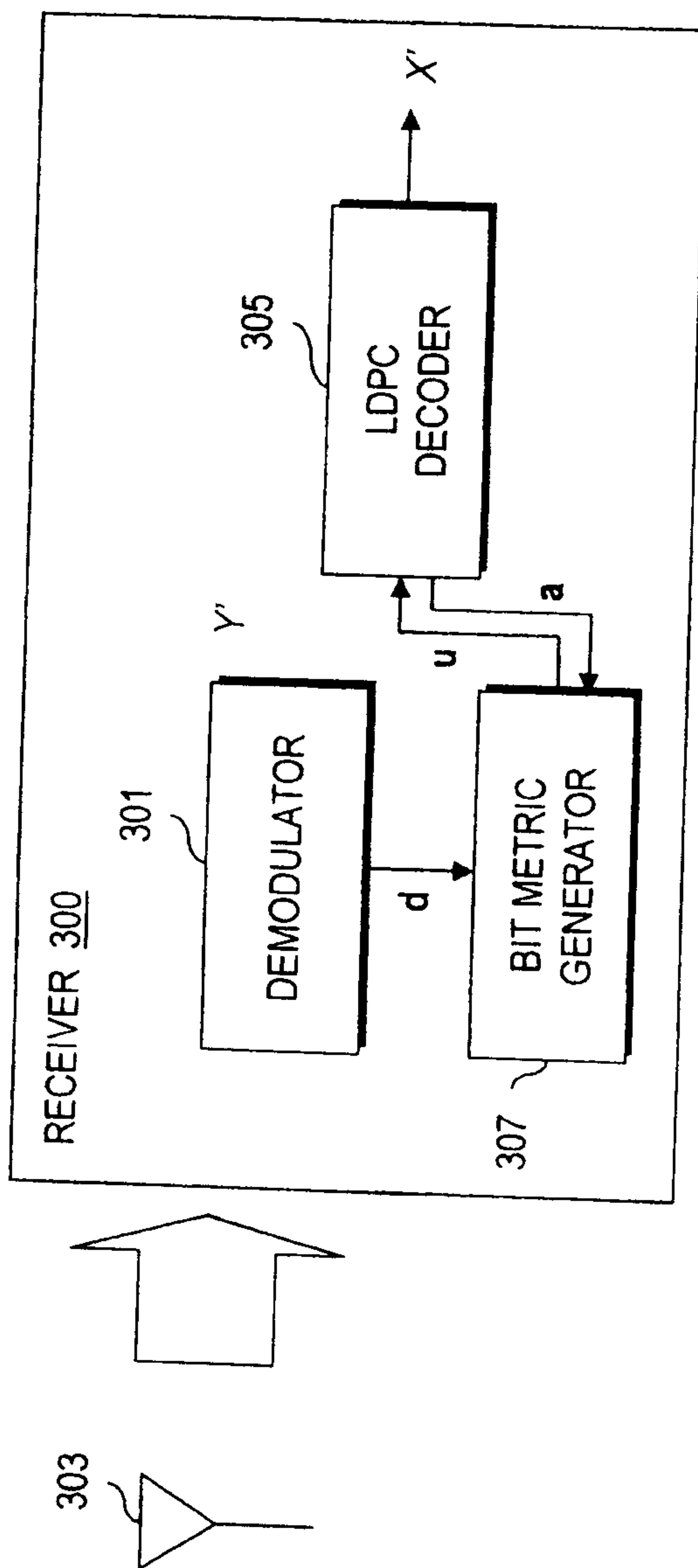
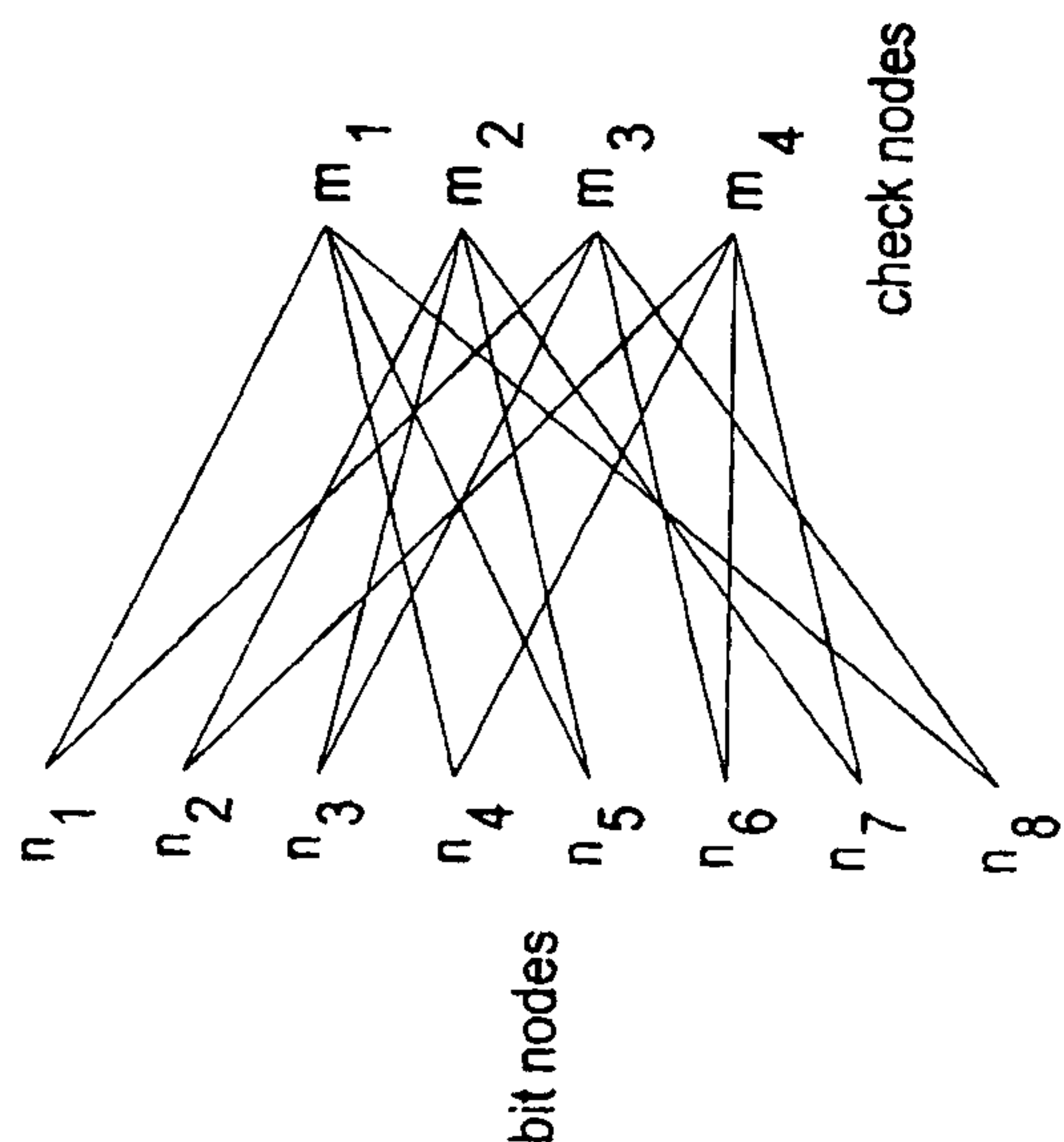


FIG. 4

$$H = \begin{matrix} & n_1 & n_2 & n_3 & n_4 & n_5 & n_6 & n_7 & n_8 \\ \begin{bmatrix} 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix} & m_1 & m_2 & m_3 & m_4 \end{matrix}$$

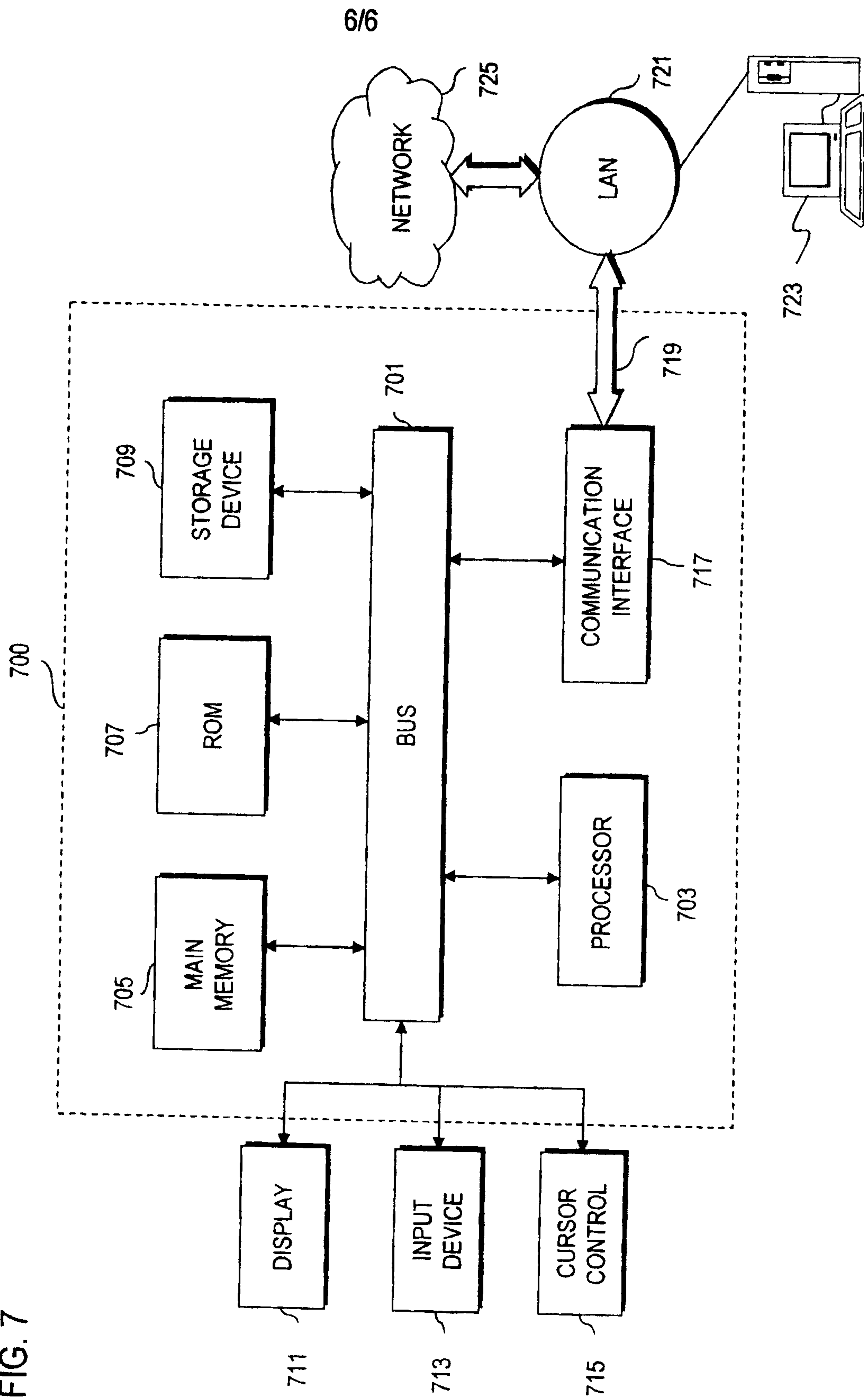
FIG. 5



$$B = \begin{bmatrix} 1 & & & & & & & \\ & 1 & & & & & & \\ & & 1 & & & & & \\ & & & 1 & & & & \\ & & & & 1 & & & \\ & & & & & 1 & & \\ & & & & & & 1 & \\ & & & & & & & 1 \end{bmatrix}$$

FIG. 6

FIG. 7



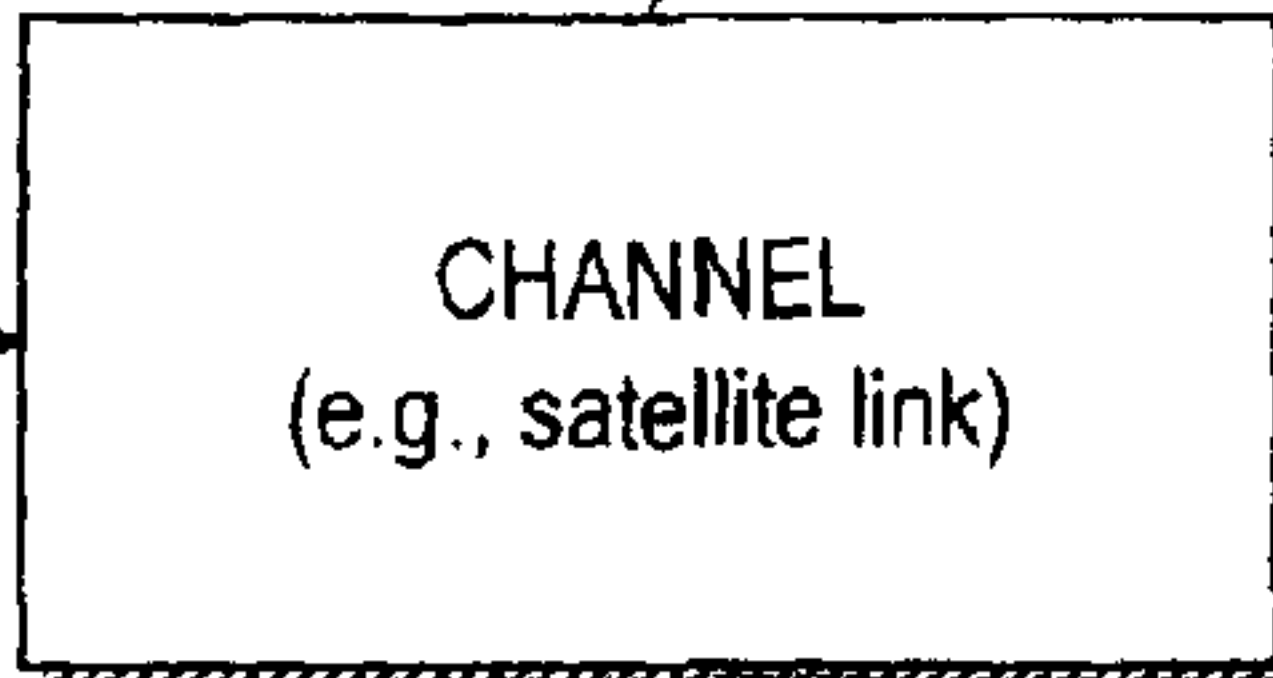
100



101



103



105

